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**STUDY OF TIME-LAPSE PROCESSING  
FOR DYNAMIC HYDROLOGIC CONDITIONS**

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16. Abstract <p>The objective of the research was to investigate the usefulness of dynamic display techniques in exploiting the repetitive nature of ERTS imagery. A specially designed Electronic Satellite Image Analysis Console (ESIAC) has been developed and employed to process data for seven ERTS principal investigators studying dynamic hydrological conditions for diverse applications. These applications include measurement of snowfield extent and sediment plumes from estuary discharge, playa lake inventory, and monitoring of phreatophyte and other vegetation changes.</p> <p>The ESIAC provides facilities for storing registered image sequences in a magnetic video disc memory for subsequent recall, enhancement, and animated display in monochrome or color. The most unique feature of the system is the capability to time-lapse the imagery and analytic displays of the imagery. Data products have included quantitative measurements of distances and areas, binary thematic maps based on monospectral or multispectral decisions, radiance profiles, and movie loops.</p> <p>Applications of animation for uses other than creating time-lapse sequences are identified. Input to the ESIAC can be either digital or via photographic transparencies. Most of the project work was with transparencies for reasons of convenience, cost, and speed.</p>					
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## PREFACE

Stanford Research Institute furnished and operated equipment, termed Electronic Satellite Image Analysis Console (ESIAC), which was especially designed to process ERTS imagery collected by various participating investigators in the U.S. Geological Survey for the Program in Dynamic Hydrology. This Final Report describes the Electronic Satellite Image Analysis System (ESIAC) and its capabilities with respect to information retrieval of ERTS data. Examples of the types of products supplied to the participating investigators are presented, but no attempt is made to describe their import to the individual research programs since that will be reported by the participating investigator himself. One of the principal products of ESIAC is the time-lapse analyses. Examples of this product are presented in two movies\* made at SRI for this purpose and previously submitted to NASA. These movies are hereby made part of this Final Report.

### A. Objectives

- To provide information on dynamic hydrologic phenomena of interest to the ERTS investigators.
- To determine requirements and costs for future on-site electronic data processing.

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\* ERTS Imagery: Examples of Viewing/Measuring via Electronic Techniques. USGS (WRD) Program in Dynamic Hydrology, NASA Contract NAS5-21841. Both movies bear the same title but refer to different time periods.

#### B. Scope of Work

- To develop methods of dynamic information extraction and processing that might be common to all ERTS investigators, with emphasis on the use of image time-lapse sequences and electronic multispectral image change detection procedures.
- To carry out such data processing as required by the participating investigators in the USGS Program in Dynamic Hydrology.

#### C. Conclusions

The ESIAC analysis capability has been of significant help to investigators interested in converging upon a quantitative description of the dynamics of a phenomenon of interest to them. Decisions about the efficacy of various thresholding, slicing, and ratioing algorithms can be made while watching the results on a registered time series of ERTS scenes displayed immediately, and simultaneously, both as a normal photographic image (image space display) and as two-dimensional radiance plot (color space display). Once a suitable classification algorithm had been found, first-order quantitative results for each scene can be read from the ESIAC area-measuring readout and at a cost competitive with other data extractions systems.

#### D. Summary of Recommendations

It is recommended that animated image analysis equipment possessing the general characteristics of the ESIAC be made available to earth-resource personnel concerned with monitoring dynamic phenomena or otherwise interested in fully exploiting the repetitive nature of ERTS-type imagery. The methods of dynamic, quantitative image analysis made possible by the ESIAC appear particularly well-suited to assist in monitoring of snow and ice in remote and rugged terrain. In view of the considerable economic importance of such work, it is recommended that research in this area be expanded.

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## I INTRODUCTION

### A. Program Organization and Objectives

The Atmospheric Analysis Group of Stanford Research Institute has been engaged in the NASA ERTS-1 investigations under Contract NAS5-21841, with Mr. S. M. Serebreny (PN045) as the Principal Investigator and Project Leader. In addition to doing its own research under this Contract, SRI also provided support to the U.S. Geological Survey (Water Resources Division) Program in Dynamic Hydrology. The organization of this program is shown in Figure 1. It is evident that the Program in Dynamic Hydrology is composed of highly diverse disciplines and fields of interest.

The SRI role in this program has been to:

- Provide information on dynamic hydrologic phenomena of interest to the ERTS investigators.

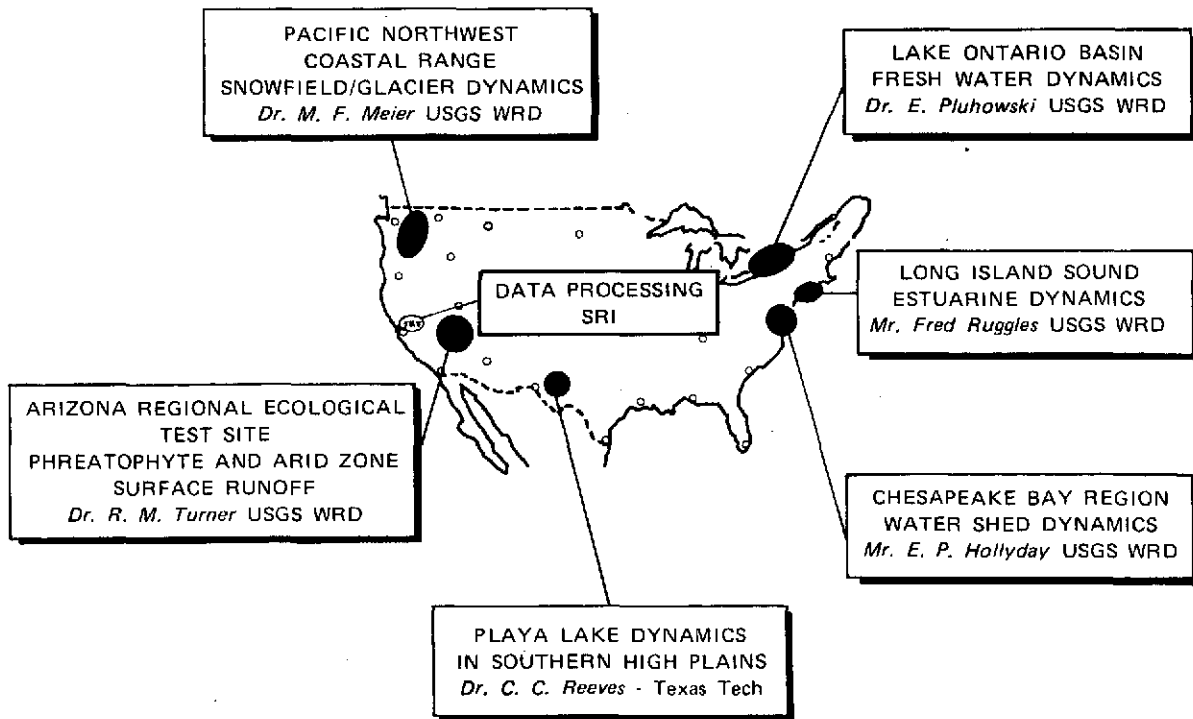


FIGURE 1 PROGRAM IN DYNAMIC HYDROLOGY

- Determine requirements and costs for future on-site electronic data processing.

## B. Research Tasks

The tasks imposed by this contract were twofold:

- (1) In pursuit of SRI's own research mission, to develop methods of dynamic information extraction and processing that might be common to all ERTS investigators, with emphasis on the use of image time-lapse sequence and electronic multispectral image change detection procedures.
- (2) In support of the Program in Dynamic Hydrology, provide services and data products for the following areas of interest:
  - Snow Field Dynamics (Dr. Mark F. Meier)
    1. Measurement of snowpack area
    2. Temporal changes in snowpack
  - Desert Vegetation Dynamics (Dr. Raymond M. Turner)
    1. Measurement of ephemeral vegetation areas
    2. Short-term changes in vegetation covered areas
  - Estuarine Dynamics (Mr. Fred Ruggles)
    1. Detection of heated water discharge
    2. Water quality
  - Fresh Water Dynamics (Dr. E. Pluhowski)
    1. Measurements and detection of shoreline and beach erosion.
    2. Enhancement of water quality as affected by sediment plumes due to man's activity and extraneous water sources.
  - Playa Lake Dynamics (Dr. C. C. Reeves)
    1. Census of playa lakes
    2. Temporal changes in water supply
  - Watershed Dynamics (Mr. E. P. Hollyday)
    1. Detection and measurement of vegetation, snow, and massed works of man within a drainage basin.

## II METHODS OF DYNAMIC DATA EXTRACTIONS AND PROCESSING

### A. Electronic System Image Analysis Console (ESIAC)

SRI has had an ongoing development program over the past two years of an interactive system called Electronic Satellite Image Analysis Console (ESIAC) for information retrieval and data processing from ERTS data. A recent photograph of the ESIAC is shown as Figure 2.



FIGURE 2 PHOTOGRAPH OF ESIAC

## 1. Objective

In brief, the basic objective of the ESIAC system is twofold: To enhance or delineate the phenomena of interest and extract quantitative measurement of it. Experience under this contract has indicated that, on occasion, the display function alone can contribute enough to understanding of the phenomena that no more output information is required, but in the vast majority of cases there was a need for the second function--that of extracting quantitative measurements from the imagery.

## 2. History of Development

The initial version of ESIAC began in December 1969 under NASA Contract NAS5-11652 as a system designed and constructed to enable precise sequential registration of ATS cloud images from which time-lapse sequences could be provided. Upon the introduction of the Earth Resources Technology Satellite, it became apparent that the system, with some additional functions, would be useful in the analysis of the ERTS data. In September 1972 under NASA Contract NAS5-21814, additional special circuitry was introduced into the system for radiance analysis of the ERTS imagery through density slicing techniques. In November 1972 a high quality TV Monitor (Tektronix Model 650-1) was produced and mated with the console so that either two-primary or three-primary additive color displays became possible. At the same time, the density slicing capability of the original equipment was improved by the addition of several more level decision circuits together with high-speed logic for combining their outputs. By September of 1973, three important and final equipment additions were made which gave system capability for: (a) reference gray scale storage on the same video disc track as the main image, (b) temporary storage of binary mask data through the use of a semiconductor memory (scratchpad memory), and (c) a two-dimensional color space display for dynamic multispectral analysis.

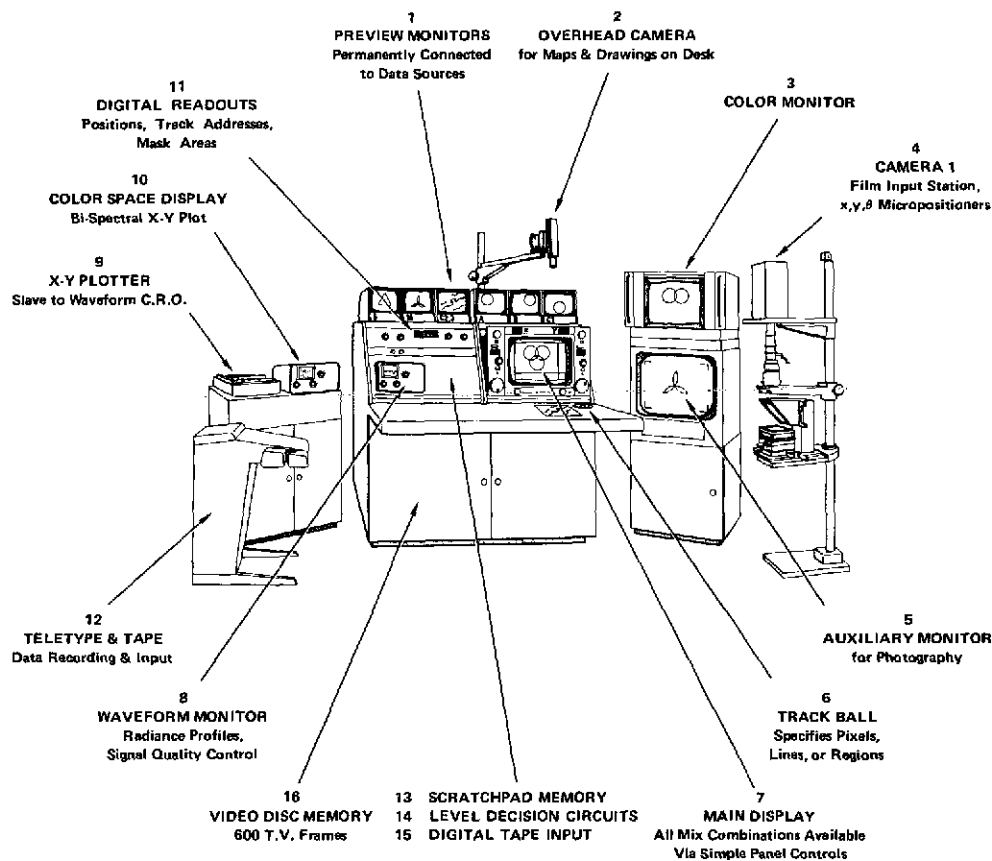
### 3. General Description

The ESIAC (Electronic Satellite Image Analysis Console) uses television scanning, storage, editing, and animation techniques to facilitate rapid qualitative and quantitative analysis of satellite imagery.

The principal feature is the ability to exploit the temporal dimension of repetitive satellite coverage, as provided by ERTS or SMS. This is typically accomplished via time-lapse presentations, but many of the functions required for time-lapse are equally useful in performing a wide variety of image comparisons, such as relating scenes to maps, to thematic extractions, and to other views of the same scene. Numbers in parentheses in the following description refer to callouts on Figure 3, which shows the equipment configuration.

Normal input is via film transparencies that are scanned by a quality vidicon camera (4). Zoom optics and an extensive system of micropositioners permit scaling of the image and precise registration to scenes or sequences already stored in memory. Images are stored on an analog video disc memory, which has a capacity of 600 full TV frames, often handled in pairs to provide 300 bispectral frame pairs. Stored frames can be accessed sequentially in milliseconds, or randomly in seconds. A fast digital-to-analog interface and cable link to a nearby computer provide a means for loading the disc memory with raw or processed images derived from digital tape.

Storage and handling of the images as TV signals permit quantitative measurements to be made with useful precision at a small fraction of the time and cost required for a fully digital system of comparable versatility. Measurements and logic decisions can be made on radiance data pertaining to any region of the scene while it is being viewed as an image.



NOTE: Numbers keyed to descriptions in text

FIGURE 3 ESIAC EQUIPMENT CONFIGURATION

An array of small preview monitors (1) continuously displays the contents of the major data sources. The operator uses simple switching and mixing controls to merge positive or negative amounts of imagery from the data sources into a composite image on the main viewing screen (7). Alternatively, the operator can rapidly switch the display between any two data sources to provide flicker comparisons-- a very powerful procedure for accentuating small differences. He can also cycle through stored image sequences to generate a time-lapse display and can adjust the animation timing to keep time with mental assimilation.

The color monitor (3) greatly magnifies the possibilities for data presentation. While complete flexibility is provided for programming signals to all three guns of the color CRT, in practice it is often desirable to limit the possible combinations in order to avoid confusion. An arrangement that has been found applicable to a wide variety of multispectral applications has been to operate with a two-primary system. Visible band images are stored on the "A" side of the memory disc (tracks A0 through A300) and are displayed in cyan (green plus blue). Concurrent infrared images are stored on the "B" side of the disc (tracks B0 through B300) and are displayed in red. Since the moving record/reproduce heads on both sides of the disc can be stepped simultaneously, bispectral time-lapse presentation is then possible.

#### 4. Additional Functions

Overhead Camera (2)--An auxiliary vidicon camera fitted with zoom optics is suspended over the horizontal worksurface. While it can be used for hard copy data entry, its more usual function is to achieve temporary superposition of maps on the displayed image for orientation. Equally useful is its function in output recording. Line drawings sketched on a notebook page or other paper located on the desktop appear merged with the display image without parallax, and features too subtle to photograph well can be documented by hand drawing directly on the paper.

Auxiliary Monitor (5)--The 17-inch monochrome display can be connected in parallel with any of the other displays to facilitate photographic data taking. It is also often used to hold a reference picture for side-by-side comparison to other displays.

Track Ball (6)--The operator controls the position and size of the digitally derived measuring cursor by means of this device. The cursor can be made to appear in several forms (cross, dot, box, box



outline) and is used to measure linear displacements. It can also be used to specify individual pixels or rectangular pixel groups within the image for measurement, rerecording, or other special consideration. The cursor location can be intensified on any or all monitors to help in coordinating the displayed data.

Waveform Monitor (8)--A dual-channel oscilloscope is used to display video signal amplitude versus time for various level setting and supervisory needs. When triggered in time coincidence with the cursor, this display can function as a microdensitometer to provide a radiance profile along any specified scan line or portion thereof.

X-Y Plotter (9)--A pen-and-ink plotter is connected to the waveform monitor oscilloscope via a sampling interface unit. It permits large, sharp, hard copy records to be made of radiance profiles or any other repetitive waveform displayed on the oscilloscope. For some applications, the method provides an attractive alternative to photographing the main TV viewing screen.

Color Space Display (10)--This display generates a two-dimensional scatter diagram depicting the distribution of radiances in any two spectral bands for the entire image or selected portions of it. Thus, the display is of immense help in adjusting the various ratioing and thresholding controls needed to generate such extractions (see Section II-C). In a typical application, vertical (y axis) displacements are caused to be proportional to infrared radiances at the same time that horizontal (x axis) displacements are made proportional to radiances in a visible band. For imagery such as ERTS, where reference gray scales are available on the film, a unique data entry procedure permits radiometric calibration ticks to be added to define both axes and the 45° diagonal. The two-dimensional color coordinates of any pixel or small group of pixels (as specified by the cursor intersection in the main image display) can be read directly from this graphic

presentation in units linearly correctable to absolute radiance values for the scene.

Digital Readouts (11)--Numerical displays are provided for cursor location, disc addresses, and area measurements (white pixel count within a thematic mask). Upon command, these readings can be recorded via teletype and paper tape (12).

Scratchpad Memory (13)--One full frame of digital image storage is provided in addition to the storage provided on the magnetic video disc. This fully addressable memory stores an array of 520 lines  $\times$  400 elements  $\times$  one bit. Thus, it has no gray-scale capability, but is used principally for temporary storage and editing of line-type overlays and binary thematic masks. Masks created objectively by machine processing of the image data can be revised or "cleaned up" by the analyst/operator using light pen or cursor control. This memory is also useful in storing "keying" or control masks required when measurements are to be confined within some irregularly shaped area, a drainage basin for example.

Level Decision Circuits (14)--Four of these LDCs are provided. Each is a fast, one-bit analog-to-digital converter with a manually adjustable decision threshold. They are used to generate binary thematic masks in accordance with simple mathematical operations on the input video waveforms. The binary outputs can be combined logically to create a mask--for example, white or TRUE for all regions of the image where the visible band radiance is greater than X percent of full scale and the infrared radiance is between Y and Z percent of full scale. The LDCs can also be used to create masks based on ratios of responses from two different spectral bands.

Digital Tape Input (15)--An interface unit and associated cabling is provided to permit loading the disc memory with image data from digital tapes handled by a nearby PDP-11 computer facility.

Loading of a complete TV image can be accomplished in a minimum of 17 seconds. While image manipulation during the data transfer is limited to simple scaling and x-y translation functions currently, any desired amount of digital preprocessing can be performed in separate operations prior to the transfer.

## 5. General Performance Specifications

General performance specifications are presented in Table 1.

### B. Radiometric Analysis by ESIAC

In the ESIAC, while input can be from tape, the normal data sources are 70 mm positive film transparencies. The system scans all or selected portions of these images with a high quality television camera, and has provision for storing several hundred TV frames in precise register on an analog video disc memory. At the same time that the scenes are being viewed as images, the scene radiance data is continuously available in electrical form, ready to be measured or operated upon. By scanning and storing the ERTS gray-scale calibration step tablets along with the images, an operator is then able to make radiometric measurements on the images with a relatively high degree of accuracy.

#### 1. Analysis of Single-band Radiometry

One objective procedure that received considerable attention was to operate on the brightness, or radiance, data contained in the single-band records. This procedure is simple and is being used or contemplated by numerous investigators. When used for area measurement purposes, it involves selectively separating all portions of an image that exceed some specified brightness or radiance value within a single spectral band. Thus, the general principle is similar to that used by others who employ electronic or photographic "density slicing." A key

Table 1

## GENERAL PERFORMANCE SPECIFICATIONS

Scanning standards	Broadcast TV; 525 lines/frame, 30 frames/second, 2:1 interlace
Video disc storage capacity	16-in. magnetic disc, two movable heads, each covering 300 tracks (TV frames), plus one fixed head for synchronization
Display horizontal resolution	Approximately 350 picture elements per picture width, limited by the video disc memory bandwidth of 4 MHz
Cursor resolution	660 steps horizontally and 490 steps vertically (for unblanked portion of raster)
Gray scale capability	Determined chiefly by the signal-to-noise ratio obtainable from the video recorder (specified at 40 dB). With care, all ten steps of the gray scale on the standard TV test pattern can be resolved
Picture slewing rate	Variable: 0 to 15 frames/second either direction
Data sources	Camera 1 (local)
Positive or negative amounts of any 4 can be mixed simultaneously on the main monitor	Camera 2 (remote) Camera 3 (overhead) A disc output B disc output Thematic mask Scratchpad memory Cursor Rectangular grid
Positioning repeatability for source transparencies (film)	Less than $\pm 0.001$ in.
Field coverage of camera 1	Continuous zoom over 10:1 range. Range is shiftable by means of various auxiliary lenses. Typical coverage range used for ERTS 70 mm transparencies: Max zoom-- $9.3 \times 5.5$ mm; Min zoom-- $72 \times 54$ mm; Illuminated light table-- $103 \times 80$ mm; Hard copy--up to several feet.
Solid state "scratchpad" memory capacity	520 TV lines at 400 bits/line
Digital computer interface	6400 bit Buffer Memory (8 bits/pixel, 800 pixels/TV line) Output Rate, $12.6 \times 10^6$ pixels/sec. Input rate, limited by connected computer and/or tape. For PDP-11, maximum transfer rate is 1 TV line/disc revolution, 16.3 sec/frame

difference is that the ESIAC provides a convenient means for the operator to continuously and critically compare the thresholded mask with the original scene image, in full tonal range and sometimes in color, while he is adjusting the threshold. Thus, the system attempts to combine the better features of conventional photointerpretation with the quantitative precision of electronic thresholding and area measuring.

The procedure is best demonstrated by example of snow measurements made for Dr. M. Meier, but is equally applicable to whatever theme (snow, vegetation, or water) is desired.

In Figure 4, the left-hand upper TV display shows a band 5 image of the Thunder Creek basin in its full tonal range. The lower trace of the oscilloscope display shows the TV video waveform for the particular scan line near the center of the scene which is shown intensified in the image display. Black level is indicated by the two flat sections at each end of the line, and upward displacements from that level indicate increasing scene radiance. Convenient controls permit the operator to compare this waveform to a manually adjustable threshold in an amplitude comparator circuit, and to derive the bi-level waveform shown on the upper trace (both waveforms are for the same scan line). For this picture, the decision threshold was adjusted to be the horizontal centerline of the oscilloscope. Note that whenever the lower waveform goes above its centerline threshold, the upper waveform is high. Whenever it does not, the upper trace is low. This binary video waveform is used to generate a two-level raster image shown in the right-hand TV display, and this is the snow map. The operator superimposes these two images on a third display (not illustrated) and adjusts the threshold until he obtains an optimum fit to the snow line--taking into account as much subjective interpretation as he can supply.

When measurements are to be taken over a specific area, a map of the area is sized and registered to the satellite image using

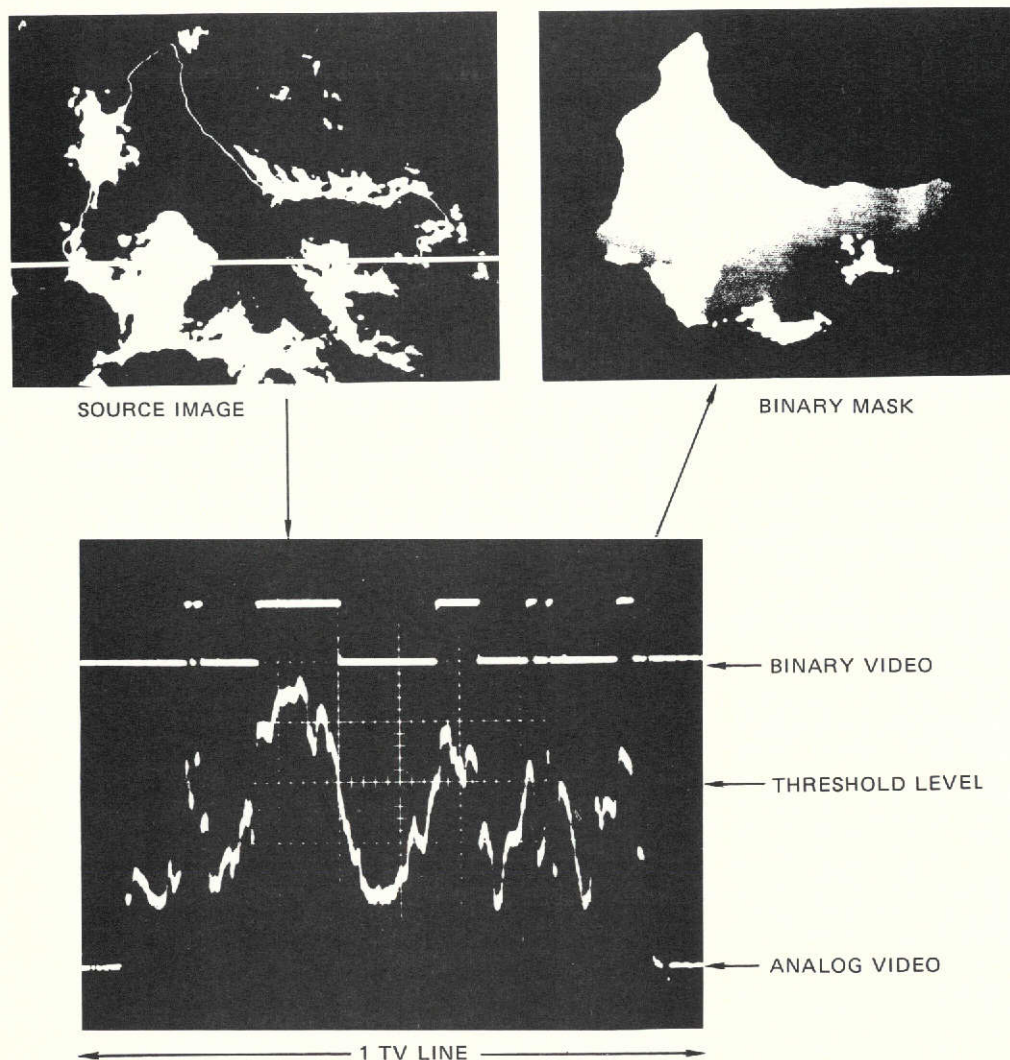


FIGURE 4 EXAMPLE OF CREATION OF BINARY SNOW MASK BY AMPLITUDE THRESHOLDING OF THE ESIAC TV WAVEFORM

Display shown is a small section of the MSS-5 record of ERTS Image 1041-18253 of 2 September 1972. The Thunder Creek Drainage Basin outline has been electronically superimposed. The analog video waveform is for the single horizontal scan line shown intensified in the upper left figure. Note that when the video waveform is above the threshold level (bright portions of image) the binary signal is "high." The binary video is logically combined with a stored binary basin outline map, and then used to generate a binary map (mask) and to control a digital counter which totals the areas-above-threshold within the basin.

the zoom and micropositioning features of the TV input station, and stored for reference on the video disc. (For this process too, the flicker and time-lapse capabilities afforded by the video storage system are of tremendous help.) Using the snow theme, as an example, by thresholding the map with one level decision circuit while thresholding the snow scene with another, then logically ANDing the resulting two binary signals, the system counts only those pixels which pass both the snow-no-snow and the basin boundary tests. The total number of white picture elements in the mask are summed in a binary counter. While this count provides a valid measure of the total area of white in the mask, how valid the count is a measure of the true snow area is critically dependent upon how well the operator set the threshold level.

## 2. Analysis of Two-Band Radiometry

### a. Color-mapping

Of the numerous functions available on ESIAC, one of the most informative has been the Color Space Display (see Section II-A4). Color mapping provides a dynamic version of the two-dimensional scatter diagram frequently used for analysis of two-band radiometry. This procedure is accomplished through the use of an oscilloscope with matched wideband x and y deflection amplifiers, connected as shown in Figure 5.

While any two synchronous video signals can be so displayed, a typical situation is for the ESIAC to be used to display a time-lapse sequence of additive pseudo-color images derived from two different MSS channels. A particularly useful combination for many applications is to display on the color TV monitor one of the infrared images (MSS 6 or MSS 7) in red and one of the visible images (MSS 4 or MSS 5) in cyan. While this display is being scanned in normal TV raster fashion, the spot on the x-y oscilloscope is being continuously positioned in accordance with the instantaneous response in the two

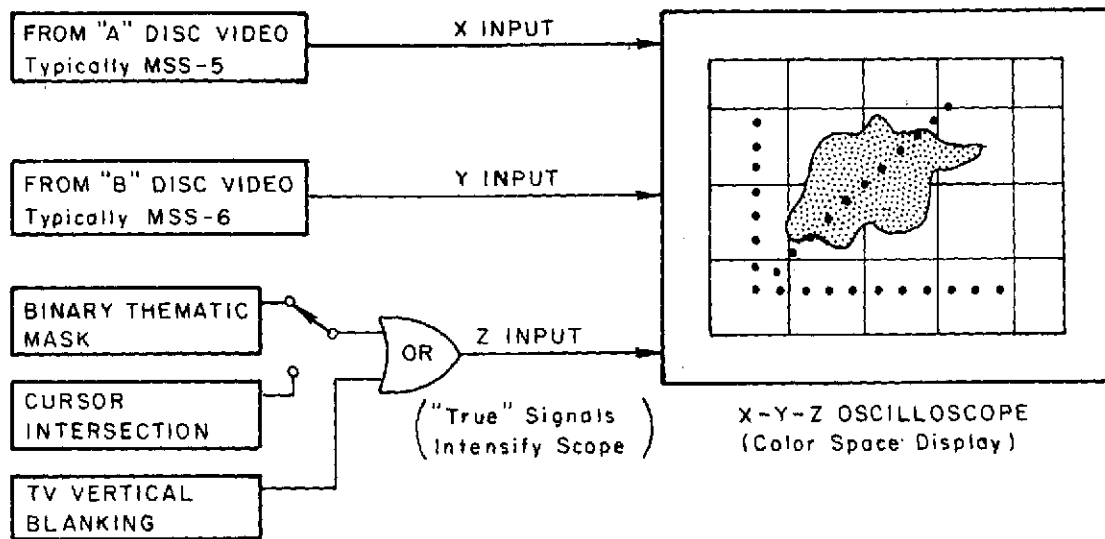


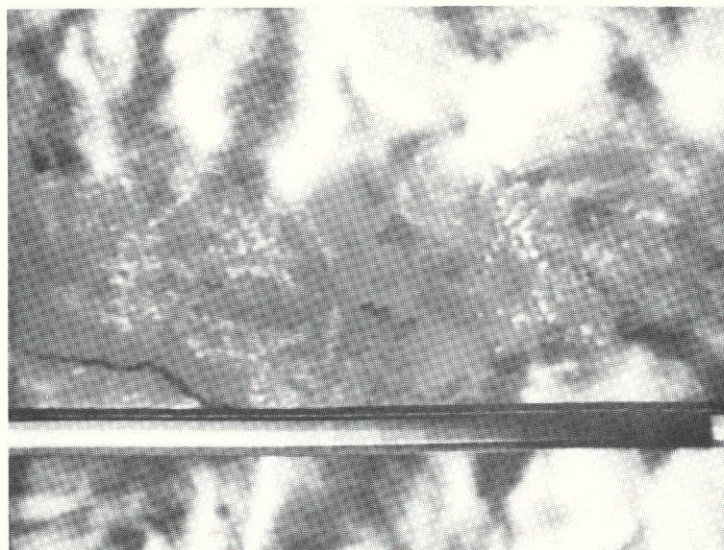
FIGURE 5 OSCILLOSCOPE CONNECTIONS FOR COLOR MAPPING DISPLAY

image channels. (We refer to the TV display as the "image space display" and to the latter x-y oscilloscope display as the "color space display.") All points in the image which generate equal responses in the two channels will be distributed ("mapped") along a  $45^\circ$  diagonal line in the x-y color space display. Zero response is located at the origin in the lower left corner.

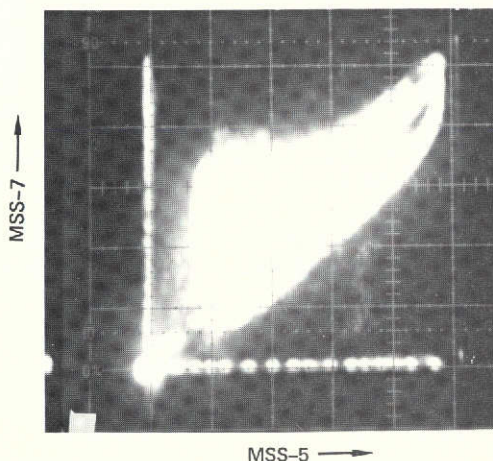
When activated for a complete image, the brightness distribution over the color space display provides a measure of the color or energy distribution for the image; that is, two-band video information is converted into a two-dimensional scatter diagram (Figure 6). Considering specific applications, scenes containing significant areas of snow or clouds (panel a) produce maps showing appreciable energy distributed along the "neutral" diagonal (see panel b). On the other hand, a heavily vegetated scene will generate a scatter diagram ("map") with most of its energy above and to the left of the diagonal. Water bodies normally map into the lower right region.

By providing intensification (z axis modulation) to the color map display only during the cursor intersection period, any

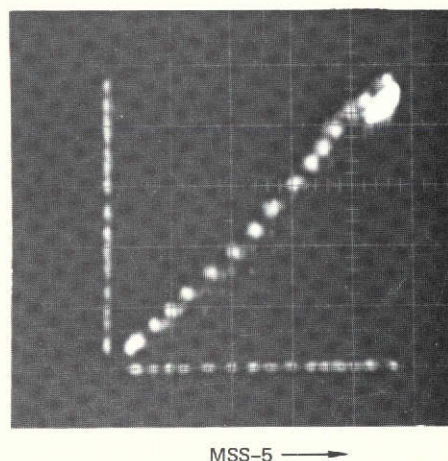




(a) PHOTOGRAPH OF IMAGE SPACE DISPLAY (COLOR TV MONITOR) FOR PORTION OF ERTS SCENE, 1313-15150, DISMAL SWAMP, NORTH CAROLINA/VIRGINIA 1 JUNE 1973 (MSS-7 SHOWN IN RED, MSS-5 IN CYAN, PICTURE HEIGHT = 53 km) (IMAGE HAS BEEN "ROLLED" (DISPLACED VERTICALLY) TO SHOW CALIBRATION GRAY SCALES STORED ON DISC DURING THE NORMAL TV VERTICAL RETRACE INTERVAL)



(b) COLOR SPACE DISPLAY FOR ENTIRE SCENE OF (a). NOTE HEAVY ENERGY CONCENTRATION ALONG 45° DIAGONAL DUE TO CLOUDS



(c) SAME COLOR SPACE DISPLAY AS (b) EXCEPT UNBLANKED ONLY DURING A PORTION OF ONE OF THE BRIGHT CLOUDS

FIGURE 6 EXAMPLES OF IMAGE SPACE DISPLAY AND COLOR SPACE DISPLAY

designated subregion of the ERTS image becomes identifiable on the color map, and its color coordinates (percent response in each of the two channels) can be read.

In Figure 6-c, the color space display was unblanked only during scan of one of the brighter clouds, and shows that the cloud generates a near-maximum response in both channels. Figure 7 illustrates the spectral signature of selected portions of an ERTS scene showing the distinction between vegetation and water, and even between clear water and turbid water. Use of the color space display and the time-lapse capability together has provided an extremely useful analytical procedure.

For example, leaving the cursor positioned over a vegetated area while cycling through a long sequence of registered images provides a rapid and dramatic portrayal of the changing spectral responses of the vegetation patch as it proceeds through its seasonal changes.

b. Generation of Reference and Calibration Axes

The dotted axes and 45° diagonal scene in the color space display (see Figures 6 through 7) are an additional bonus resulting from the way the image gray-scale tablets are handled in the ESIAC. This process will now be described.

In order to prevent the loss of a recorded radiometer scale reference when small "zoomed in" section of full ERTS frames are being viewed, it has become standard practice to record a minimum zoom image of the full gray-scale tablet of the source of transparency during the 1.15 millisecond vertical retrace period of the main image. This is valuable recording capacity which would otherwise be wasted.

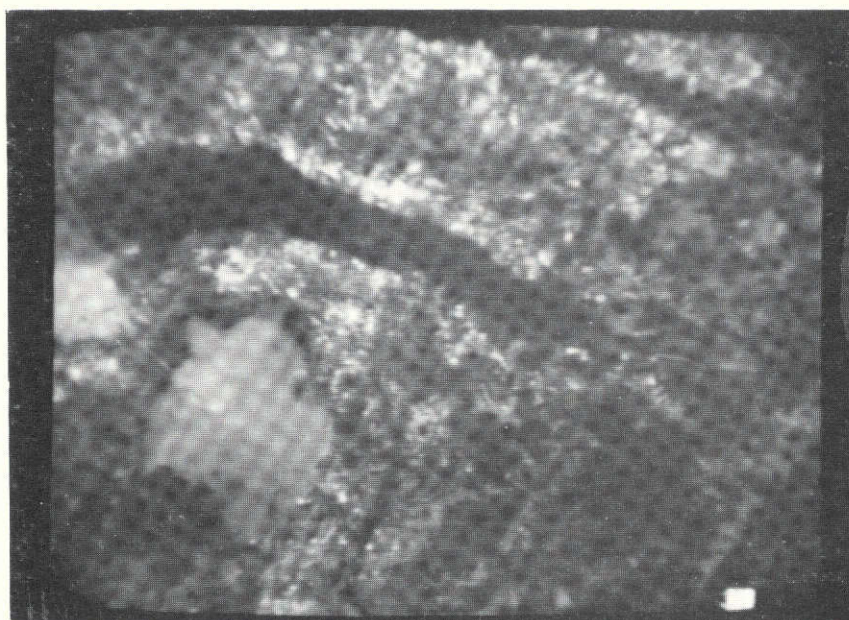


IMAGE SPACE DISPLAY (COLOR TV MONITOR) ERTS SCENE  
SANTÉE RIVER SWAMP, S.C.

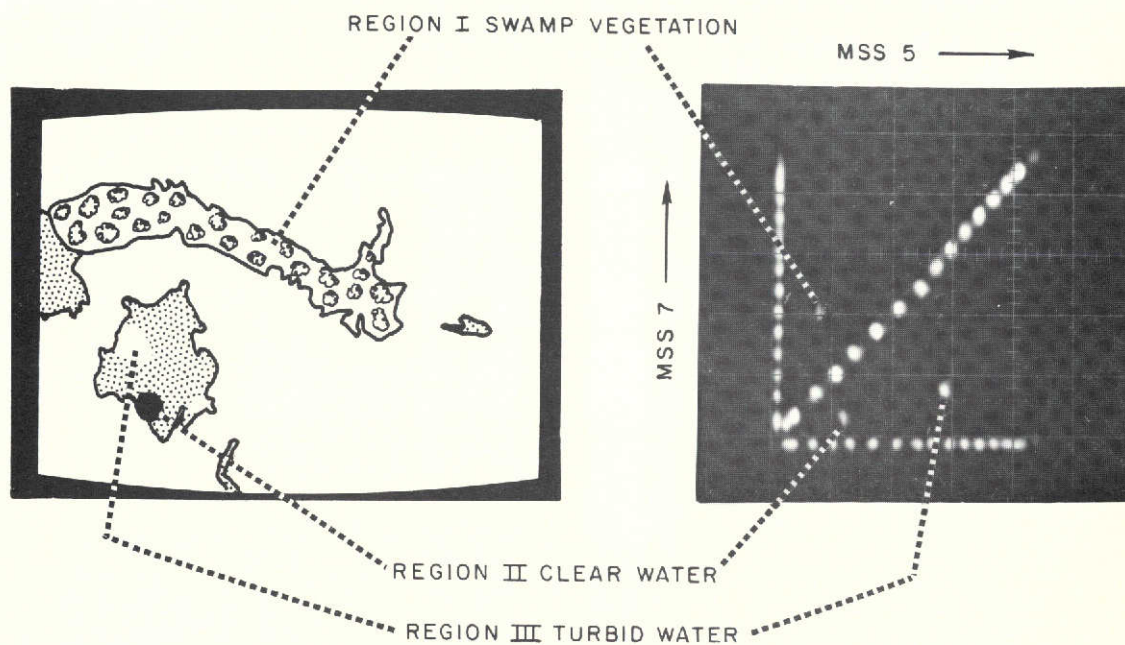


FIGURE 7 COLOR SPACE DISPLAY OF SPECTRAL SIGNATURE FROM THREE SELECTED  
SMALL GEOGRAPHICAL REGIONS WITHIN SCENE

Prior to recording, the camera controls are adjusted to compensate as much as possible for batch-to-batch variations in film processing; i.e., an attempt is made to normalize the gray scale gain, offset, and linearity. All gray scales are recorded onto disc at a fixed magnification (chosen to use nearly the full width of the raster), regardless of what magnification may be used for the scene data in the main portion of the frame.

After this dual recording process, the gray scales may be viewed on the picture monitors by intentionally misplacing the vertical sync to "roll" the image vertically. Normally, however, it is not necessary to view the recorded gray scale as an image. Its principal purpose is to provide amplitude calibration for the video waveforms; for this use, it can be accessed at any time with the console's cursor-controlled line-selector oscilloscope, even while it is blanked from the image space display during its vertical retrace period.

Additionally, the gray scale data will show up on the x-y color map display as a line of dots since this display is not blanked during the vertical retrace period. In fact, it is often desirable to actually intensify the color map during the picture vertical retrace interval in order to emphasize the color coordinate axes.

The desired effect of having the reference data be at  $0^\circ$ ,  $45^\circ$ , and  $90^\circ$  on the color map is achieved by recording the two gray scales slightly misregistered in the vertical direction. Using a combination of band 5 and band 6 as an example, there will be a brief period (several scan lines) during which only the band 6 gray scale will be scanned, another brief period during which only the band 5 gray scale will be scanned, and a third brief period during which both gray scales are scanned simultaneously (see Figure 6a). It is during this latter



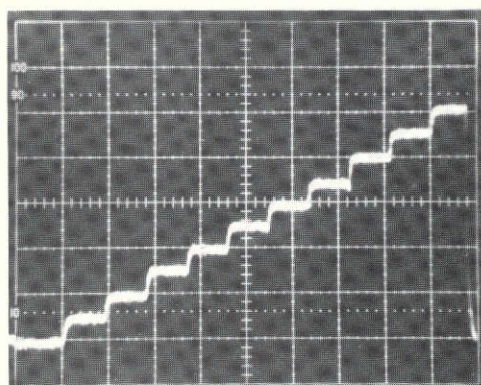
period that a color image space display will show a neutral gray scale, and the 45° diagonal line will be generated on the x-y (color space) display.

By reading the x and y coordinates of an area relative to the axial dots generated by steps on the film gray-scale tablet (interpolating when necessary), two-band radiometric values for the area can be specified in terms of absolute values--e.g., in watts-meter<sup>-2</sup>-steradian<sup>-1</sup>, with a minimum error due to amplitude nonlinearities in the photographic and TV processing steps.

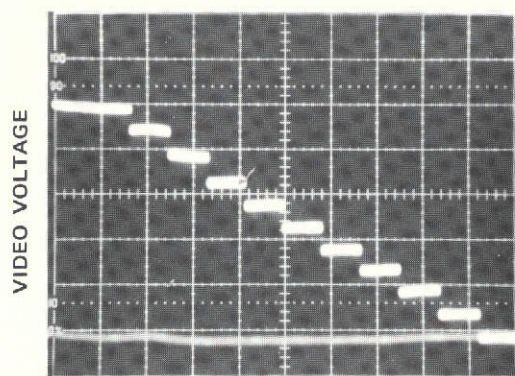
#### c. Selection of Spectral Combinations

A special two-channel test signal generator was incorporated in order to exercise the full gamut of spectral combinations possible with the recording, display, and classification equipment. Its output video waveforms, along with associated image space and color space displays, are shown in Figure 8 panels a-d. When combined into a two-primary additive color display (Figure 8e), the test pattern appears as an 11 × 11 checkerboard color palette presenting samples of all possible colors and brightness achievable with the two primaries used or, alternatively, showing the result of all possible combinations of responses in two input channels. Maximum red color saturation is in the upper left corner, maximum cyan saturation is in the lower right corner, and a scale of neutral grays runs from black at the lower left corner to maximum white at the upper right corner.

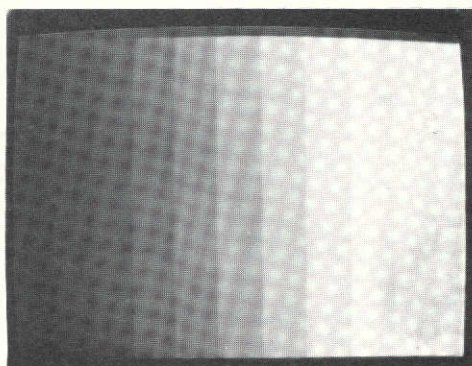
Since the display spends an equal amount of time (slightly less than 1% of the total) in generating each color patch, the color map transformation of the synthetic test pattern in an 11 × 11 array of equal intensity dots (Figure 8f). This full-gamut dot pattern greatly facilitates adjustment of the various video thresholding and slicing circuits provided in the ESIAC for generating binary masks of various



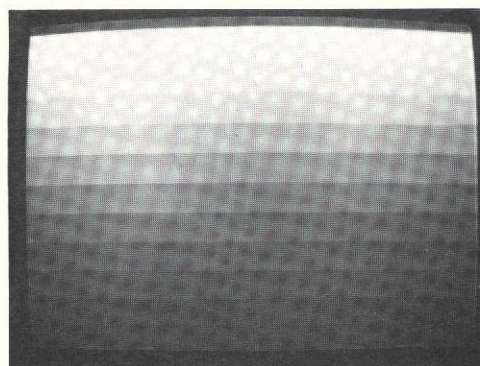
(a) CYAN CHANNEL VIDEO WAVEFORM



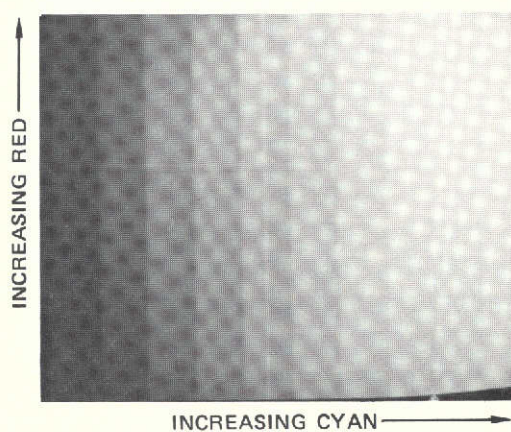
(b) RED CHANNEL VIDEO WAVEFORM



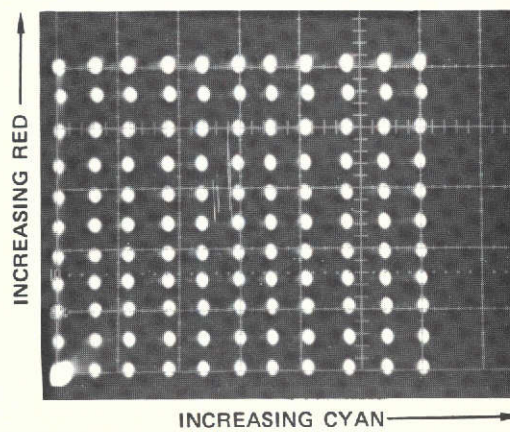
(c) CYAN CHANNEL IMAGE DISPLAY



(d) RED CHANNEL IMAGE DISPLAY



(e) COLOR COMPOSITE DISPLAY  
(Image Space)



(f) COLOR SPACE DISPLAY

FIGURE 8 VARIOUS DISPLAYS OF THE TWO-CHANNEL SYNTHETIC TEST PATTERN

image classifications or themes from real images. By watching the dot display as the thresholding levels for the thematic mask are changed, the system can be quickly tailored to respond only within some particular subregion of the color space.

d. Theme Extraction: Slicing and Ratioing

The several panels of Figure 9 illustrate some of the thematic extractions that are possible through manipulation of the video slicing and thresholding controls. In all cases, those spectral combinations that pass the classification tests (i.e., which can generate TRUE or white areas in the thematic mask) are shown intensified.

The same binary video signal used here for intensification of the color space display will generate a two-dimensional thematic mask when displayed in image space. Figure 10 is a black and white reproduction of the color image space display containing a superimposed (intensified) thematic mask for the same conditions used to generate Figure 9d.

These conditions might be used, for example, to extract from a color scene all the bright grays and whites (i.e., which hopefully would correspond to all the areas of bright snow and clouds).



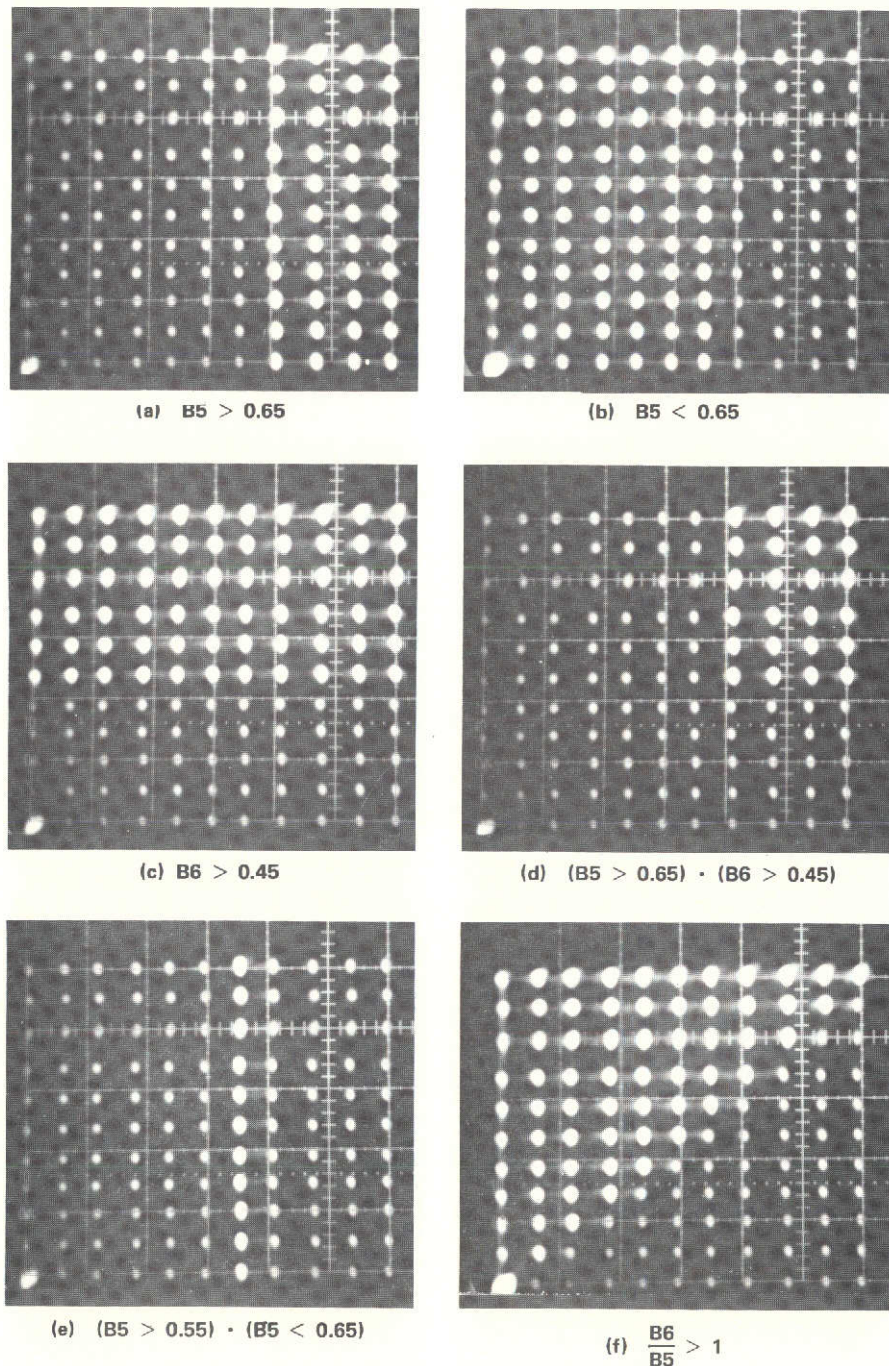
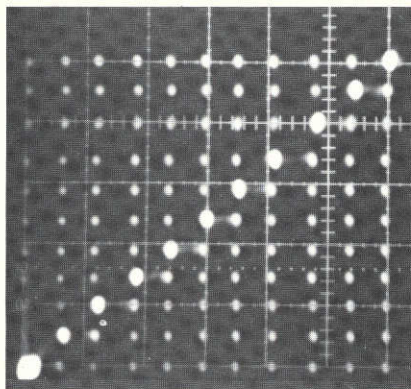


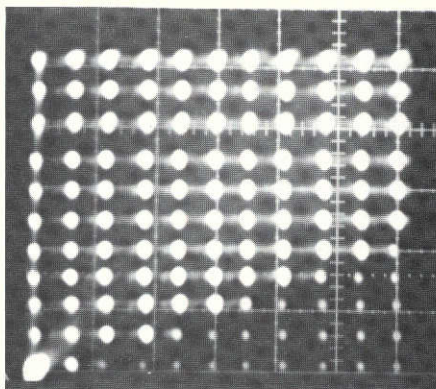
FIGURE 9 A SAMPLING OF THE SPECTRAL CLASSIFICATION AVAILABLE BY VARIOUS LOGICAL COMBINATIONS OF THE VIDEO LEVEL DECISION CIRCUITS (LDC'S) IN THE ESIAC

In each case the color map is intensified for all input signal combinations satisfying the logical equations given.  $B5 = \text{MSS-5} = \text{horizontal deflection}$ ,  $B6 = \text{MSS-6} = \text{vertical deflection}$ .

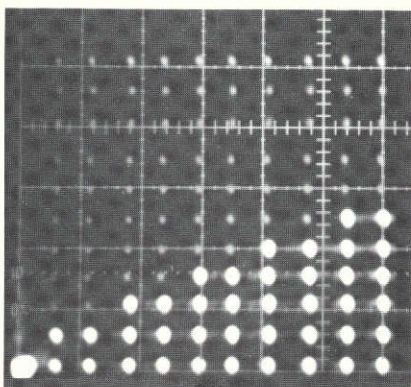




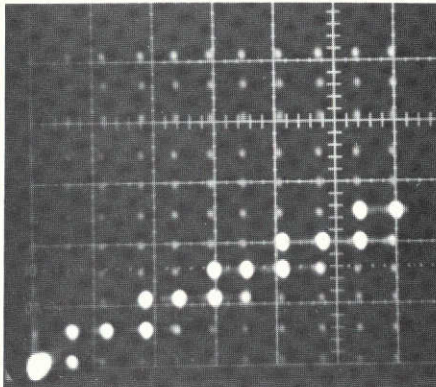
(g)  $(B6 > B5 - 0.05) \cdot (B6 < B5 + 0.05)$



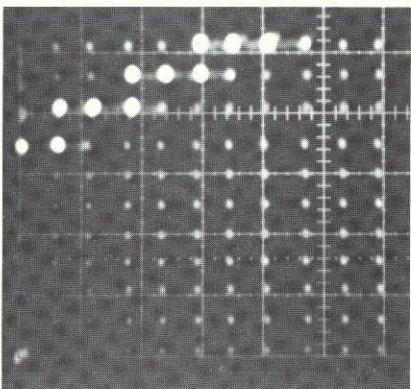
(h)  $B6 > (0.5 B5 - 0.05)$



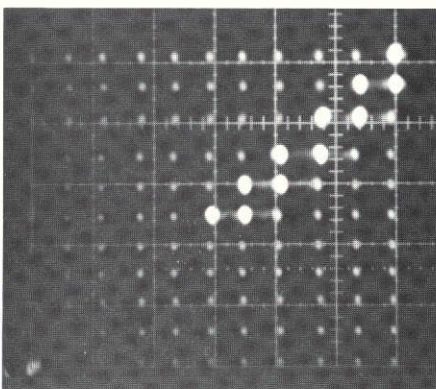
(i)  $B6 < (0.5 B5 + 0.05)$



(j)  $(B6 > (0.5 B5 - 0.05)) \cdot (B6 < (0.5 B5 + 0.05))$



(k)  $B6 > (0.05 + 0.6) \cdot (B6 < (0.05 B5 + 0.8))$



(l)  $((B6 > (B5 - 0.15)) \cdot (B6 < (B5 + 0.05))) \cdot (B6 > 0.45)$

FIGURE 9 A SAMPLING OF THE SPECTRAL CLASSIFICATION AVAILABLE BY VARIOUS LOGICAL COMBINATIONS OF THE VIDEO LEVEL DECISION CIRCUITS (LDC'S) IN THE ESIAC

In each case the color map is intensified for all input signal combinations satisfying the logical equations given.  $B5 = \text{MSS-5} = \text{horizontal deflection}$ ,  $B6 = \text{MSS-6} = \text{vertical deflection}$ . (Concluded)

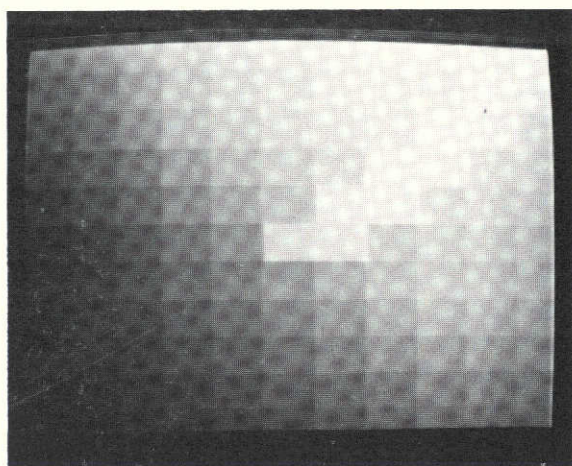


FIGURE 10    BLACK AND WHITE REPRODUCTION  
                  OF TEST PATTERN ON COLOR MONITOR  
                  (IMAGE SPACE DISPLAY)

A superimposed video thematic mask corresponding to the condition of Figure 9I delineates those areas of the image that meet the classification conditions.

### III ESIAC ANALYSIS - CONCLUSIONS AND RECOMMENDATIONS

#### A. General Observations of Analytic Capability

One of the more important tasks in the research program was to assess the usefulness of various different image analysis aids to scientists pursuing their individual research goals.

Our approach toward this end was to implement a useful variety of data analysis aids, to place these at the disposal of a representative group of scientific investigators bent on pursuing their own objectives, to make ad hoc modifications and additions to the instrumentation when genuine needs became apparent, and then to evaluate which of the features appeared to be most useful to each type of investigation. In this section we summarize the results of those observations.

The principal function of the ESIAC as initially conceived was to generate well-registered time sequences. Satisfactory procedures for registering and animating the image sequences were available from previous work with meteorological satellite imagery, and these facilities were incorporated in the ESIAC from the start. However, at best, a time-lapse capability alone can provide only an impression to the eye and mind of one or a few observers. Almost invariably there is a concomitant need to quantify and document the observed results.

Thus in the present investigation, a major effort was concentrated on the more elusive topic of extracting quantitative data from the imagery, particularly that imagery which might benefit from visual enhancement by animation or false-color manipulations.

The quantitative data most often requested by the investigators participating in this experiment were (1) displacement and velocity

vectors for slowly moving geologic features, e.g., glacial moraines, ice packs; and (2) area and aerial distribution of specific themes, e.g., snow, ice, open water, vegetation, moist soil patches, sediment plumes, urban areas.

It soon became apparent to all concerned that the task of extracting specific themes from the imagery involved many subtleties, even for themes as easily describable as, for example, snow or water.

To assist in making these thematic classifications, increased emphasis was placed on implementing console features that would aid in analyzing the spectral composition of the images and aid in making classification decisions based on responses in more than one spectral band.

The functions provided in the equipment configuration that existed from about the middle of the project onward appeared well-matched to the needs of all participating investigators during this period of education and concept formulation. Virtually all features were well-exercised; there were very few times when the progress of an investigation appeared to be paced by equipment limitations, yet the interactive controls remained conceptually simple enough that a strong feeling of being in command of the situation evolved.

The ability to try different classification algorithms while using animation to watch the effect on imagery covering several dates or seasons was of great help in the general learning process. While it was frustrating to note all the real-life exceptions to the classification rules under test, reasons for the anomalies usually were apparent. In addition, it was usually possible to infer which problems were accentuated by the instrumental deficiencies inherent in the photo-optical and analog signal processing steps, so that decisions could be made about whether it would be profitable to turn to all-digital processing.

## B. Specific Conclusions

### 1. Time-Lapse Presentations Are Nearly Always Helpful

All of the investigators, without exception, reported that the time-lapse presentations definitely helped them with the analysis and understanding of their problems, though there were definite differences in the degree of help. For example, for E. P. Hollyday (streamflow analysis), the color time-lapse presentations led to an early awareness of a useful new classification theme, riparian vegetation, in time for it to be included in his present ERTS study. The investigator felt that this theme would not have been recognized for another year or two, if at all, without time-lapse.

For Dr. Meier (glacier dynamics), time-lapse analysis of the Bering and Yetna glaciers at their joint source in the Bagley Ice Field led to an improvement in the understanding of glacier behavior--an improvement that undoubtedly would never have been apparent through study of individual images.

### 2. For ERTS Data Received Thus Far, the Advantages of Animated Display Are More Subtle and Less Immediately Obvious than, for Example, for Meteorological Cloud Sequences

Full-frame ERTS image sequences normally lack the large-scale organization (and therefore the immediate dramatic visual impact) so often evident in meteorological cloud sequences, but closer examination often reveals more subtle advantages of animation. For only one of our participating investigators--one working in relatively cloud-free Arizona--was sufficient imagery available to permit assembling long multi-season sequences of the type that first come to mind when one thinks of time-lapse presentation. Possibly as a result of this paucity of data or possibly because of the limited range of subjects studied thus far, (but more likely, we suspect, because of the inherent complexity of the

questions being asked in earth resources investigations), we found that the available animation facilities were being used far more for such tasks as comparing A to C, then B to F and G, or overlaying A on D than they were for assembling straightforward documentary sequences.

3. Preparation of Effective Time-Lapse Sequence from ERTS Is Much Easier than for Other Satellites

Preparation of well-registered time-lapse sequences was found to be very much easier and simpler for ERTS than for imagery from the synchronous meteorological satellites, or from any other satellites available to date. This is because of the constant scale size, the orthographic presentation, and the abundance of landmarks, and the relative lack of internal "rubber sheet" geometric distortions. Of particular importance when considering storage registration and manipulation in digital form is the fact that rotational adjustments are only rarely required, except when registering to maps or other non-ERTS reference imagery.

4. User Demand for Thematic Extractions Was High

The requirement for theme delineation through objective multi-spectral analysis, either for actual use or to provide assurance that a single-band analysis could suffice, was much greater than had been anticipated in preparation for this project.

This requirement, more than any other, governed the hardware additions and modifications that were incorporated during the program. The requirement also significantly modified our thinking about how to use the existing equipment, and how to allocate the available data storage capacity.

5. Rapid Access Image Storage Is Very Valuable Even for Non-Time-Dependent Studies

The multiple-frame video disc storage capability, while not used as much for long-sequence time-lapse presentations as had been originally anticipated, was in constant demand for a wide variety of miscellaneous temporary storage tasks associated with making color displays, making flicker comparisons, providing reference overlays, holding composite images and image sequences pending permanent documentation, and so on. While we have identified several special-purpose applications that can be served by a nonstorage electronic viewer and density slicer, and while we can plan the acquisition of such equipment to relieve the work load on the ESIAC, it appears clear that rapid-access multi-frame image storage is virtually mandatory for general-purpose image analysis.

6. Multiple Displays Are Very Helpful

Provision of an array of simultaneously viewable nonredundant displays was found to be an extremely powerful and efficient means of rapid information transfer, particularly during the investigation of new phenomena. When often used image components are assigned consistently to the same positions in the array of displays, operators very quickly learn where to glance to find needed data, and the retrieval is much faster and less mentally diverting than any form of electrical switching onto a single display. On numerous occasions, when several observers were present during the study of a scene or sequence, important features affecting the direction of the investigation were detected in one of the ancillary displays by one of the observers while the machine operator was concentrating on the main display. The principal system expense is in generating and storing the data. With the TV format, the incremental cost of providing additional screens to display the stored data in various forms and combinations is relatively trivial and the rewards are significant.



7. Interactive Features Were Found Necessary for Both Analysis and Data Reduction

For nearly all of the programs, two relatively distinct phases of ESIAC usage evolved: planning and data reduction. Recognition of the sometimes separate requirements of these two phases should be useful in planning the instrumentation for future programs. In planning the instrumentation for future programs, the sometimes diverse and sometimes common requirements for these two phases should be recognized and taken into account. Efficient man-machine interaction is of prime importance for both tasks--in planning, to prevent the mechanics of manipulating the image data from impeding the information transfer; and in data reduction, to yield a reasonable time schedule and error rate.

The greatest visible progress invariably was made when the principal investigator--the person who had the best knowledge of what in the scene was important and what was probably extraneous--was working with his own imagery in a "hands-on" mode. Typically, a step in this phase would be accomplished in two or three four-hour operating sessions, separated by roughly equal periods when the data file could be revised by operating technicians. Each such planning step would usually need to be followed by a considerably longer period by SRI analysts, during which the results of the planning session were more thoroughly documented, additional photographs, movies, or other records made of stored displays, and the desired numerical data extracted from numerous frames in a routine but careful manner. While we have constantly been alert for procedures amenable to automation, the extraction requests received thus far have always required subjective judgment and human guidance. As training for making these decisions, the data reduction analyst normally assists the principal investigator at the console during the planning phase.



## 8. Selection of the Type of Film Transparency Is Important

While the ESIAC provides polarity inverting controls to permit storing or viewing any image either as a negative or as a positive, there are practical advantages for choosing positive input transparencies when working principally with high radiance subjects such as snow, and choosing negative input transparencies when working with low radiance subjects such as sediment plumes in water. The most obvious reason for these choices is to keep the subject material of interest in the clearest (lowest density) part of the film so that the transmitted light will be high and permit the TV camera to operate with a good signal-to-noise ratio. In addition, because photographic reversal of film maintains the original density increments (logarithmic units) between calibration tablet gray steps, a system set up to respond linearly to film transmission will greatly expand the first few steps of the gray scale of a negative film transparency--i.e., those corresponding to the low radiance portion of the original scene--and will therefore make it easier to set and maintain video threshold adjustments in that region.

### C. Problem Areas in Theme Measurement

#### 1. Snow

The biggest problem in mapping the extent of snowcover is accounting for the low radiance snow, particularly in mountain areas. The snow radiance seen by the satellite can be low because of patchiness, low sun angle, shadowing, or partial obscuration by trees.

Extractions based on simple thresholding of single-band radiance records leave much to be desired. Basically, the problem is that while the probability is very high that all of the brightest parts of the picture are snow, a significant portion of the snow in the scene may not appear at all bright, because of shadowing and the other factors

mentioned earlier. Assuming these factors to be equal, the radiance of a snow field as seen by the satellite overhead will be proportional to the cosine of the solar incidence angle. Snow on south-facing slopes may be nearly perpendicular to the sun and thus generate a full-scale response even in the middle of winter, while identical snow on nearby north-facing slopes will exhibit radiance of only a few percent of full scale and thus almost certainly will be missed by any threshold set to exclude reasonably bright nonsnow scene elements.

One possible refinement would be to develop for each basin of interest a series of "shadow factors" that are applicable for different sun angles and percent coverage. One would measure the area of bright snow by simple thresholding in one or two spectral bands, and then increase the figure by an appropriate amount to account for snow undoubtedly present, but in shadow. However, to develop a data base adequate to generate such a library of shadow factors would require several years of ERTS imagery.

We have tried numerous refinements in attempts to reduce the subjective spread among operators, and--what is more difficult--to reduce the possible spread between our readings and what we believe to be ground truth. Other refinements are to use color for the reference scene, and to present well-registered multi-date sequences in time lapse. The ESIAC also provides an editing feature, which permits the operator to "touch up" the binary snow mask before it is measured--erasing obvious artifacts and filling in obvious voids. We had hoped that most of the extraneous areas would be sufficiently well-isolated that manual editing would be practical, but unfortunately they are not. Most of the problem occurs in precisely defining an average snow line over a relatively long perimeter. We do not yet have definitive ground truth for the closed basins during the winter-spring season when the uncertainty is greatest.

It seems clear that in using single-band radiance thresholding, there will continue to be a requirement for the operator to have a considerable familiarity both with the terrain and with satellite optics. The present procedure is considerably more tedious than we had anticipated, even with the relatively rapid image manipulation afforded by the ESIAC. A set of area measurements on a specific drainage basin for ten different dates typically occupies two operators on the ESIAC for approximately seven hours, including set-up and calibration time. The effort could be reduced without sacrificing accuracy through automation of nonsubjective chores. Both operator-to-operator variance and variance from ground truth could possibly be improved slightly through further education, experience, and care, but we feel significant improvement will require some major procedural change. Development of the previously suggested catalog of shadow factors should reduce the need for the operator to crowd the decision threshold toward extremely low values in order to include low-brightness snow.

We have tried one technique to reduce the effect of both shadowing and subjective bias: to electronically subtract a previous image from the current one before entering the amplitude decision circuits. Areas that photographed at approximately the same brightness for two passes cancelled to a mid-gray tone, regardless of whether the actual brightness was high or low. Areas in which the brightness increased during the period showed up bright in the difference image. Again, the survey is prone to omissions. Some new snow may be in areas which have recently become shadowed and will be missed, but now the required shadow factor is smaller. More importantly, by this procedure, a figure for the operationally important cycle-to-cycle change in the snowpack is obtained which is probably more accurate, we believe, than the same figure arrived at by differencing two successive estimates of overall snowpack within a basin.

Another approach is to attempt to establish the average snow-line elevation. Then, since cumulative area versus elevation data are known for most basins of practical interest, the probable snow area can be inferred and the problems of shadowing are largely eliminated.

In its simplest embodiment, one merely adds a contour overlay to the satellite picture and estimates the snowline elevation. With the ESIAC, we can simplify some of the scaling, registration, and contrast problems by accomplishing the same thing electronically.

The estimating task is made very much easier, if we arrange to apply the contours one at a time rather than all at once. Here the multi-frame storage capacity of the ESIAC again provides help. It permits one to store a registered sequence of masks enclosing all regions above the elevation shown on a label. When the operator overlays such a sequence on the satellite image, he can turn the knob up and down until he arrives at the best overall visual match to the snowline, and then he reads the elevation label. This procedure is very fast, and is one that might be implemented completely optically, with an overhead projector and a film strip.

During this contract, contours masks were prepared by hand from topo sheets, but with the digitized maps now available, it would be a straightforward task to prepare them completely by machine.

For Mt. Rainier imagery, during the first full year of ERTS we find very little disagreement among operators in locating the average snow-line to within 250 feet, which for that region amounts to a projected area variance of  $\pm 13.4\%$ . This is comparable to the best that we have been able to do on Mt. Rainier with radiance thresholding, and appreciably better than we can do by radiance thresholding in winter, when coverage is great and shadows are long. Of the numerous refinements tried, none were unconditionally successful; all were time-consuming,

and all required subjective assistance. For example, the detection of shadowed snow on north-facing slopes can be improved by accepting IR/visual radiance ratios near unity, but to accomplish this by any means short of using magnetic tape input requires band-to-band registration even better than that needed for ordinary viewing in order to properly account for all of the little indentations in the dendritic snow pattern.

The most promising approach for fully objective measurement of snow extent lies in exploitation of the multispectral data generated by the ERTS sensors. In this approach, reliance is placed on the different spectral responses of snow elements and nonsnow elements.

Generalized spectral reflectance curves for snow, trees, rocks, and glacial ice, as derived from various sources, are shown in Figure 11. However, since the satellite sensors respond to radiance and not to reflectance, these data have been converted into maximum scene radiances (Figure 12) by multiplying with standard values for solar spectral irradiance and reasonable values for atmospheric transmission over the two-way path (sun-earth-satellite) both for sea level and for an assumed 12,000 foot mountain elevation.

Further reduction of these data by applying correction factors for sensor sensitivity and spectral bandwidth (as supplied by NASA) results in the bar graphs of Figure 13.

The bars in Figure 13 summarize a sizable portion of the a-priori knowledge needed for radiometric study of the ERTS images. It can be seen, for example, that the maximum responses to be expected from mountain snow can exceed the full (100%) scale range of the system in all four bands--i.e., the system will saturate--and numerous observations have verified that this is indeed so. Since very few other surfaces found in mountain areas are capable of such high response, there is a high degree of certainty that such saturation signals can

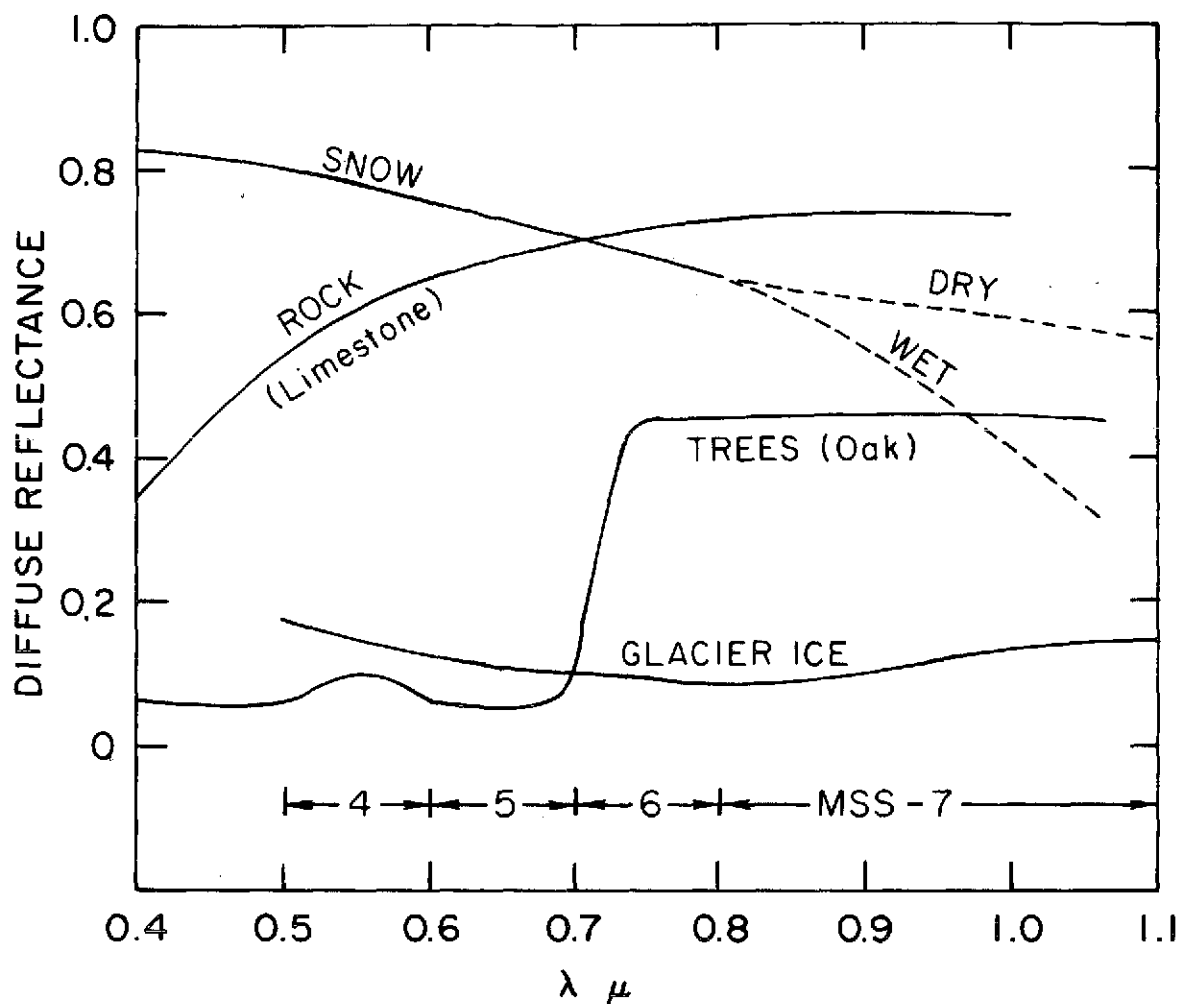


FIGURE 11 GENERALIZED REFLECTANCE CURVES FOR VARIOUS SURFACES

Data averaged from numerous references and spot checked against available ERTS imagery.

can be classified as snow. It should be kept in mind that these are maximum responses, for surfaces optimally illuminated. While all of the bars will become shorter with poor illumination and rougher texture, the relative lengths, i.e., the band-to-band ratios, should not change substantially.

While it is certainly possible for the radiance of snow in shadow to be less than 1% of snow in sun and thus generate a negligible signal, there usually will be enough fill light from sky and nearby bright slopes to limit the maximum large-area contrast to perhaps 30:1.

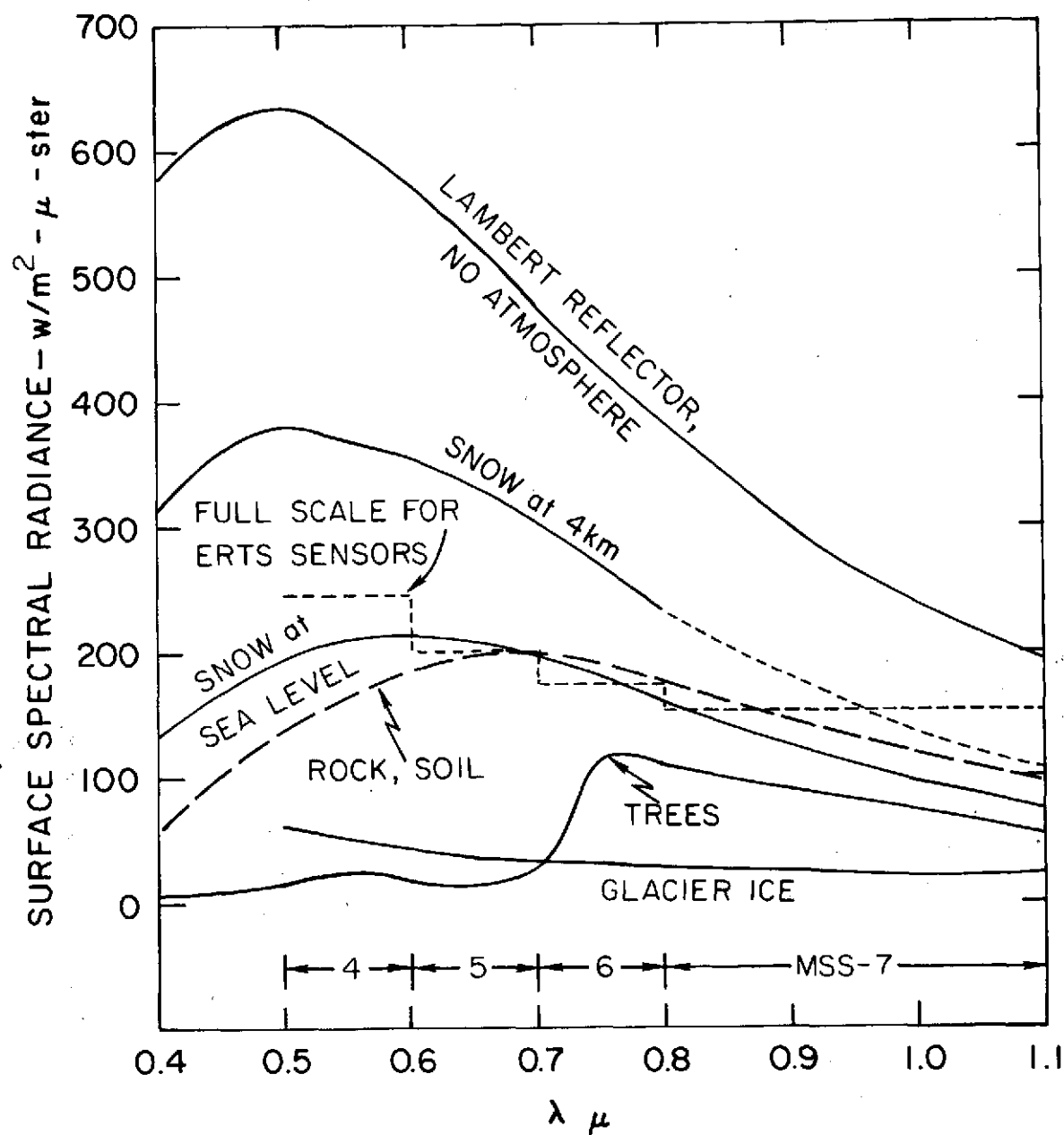


FIGURE 12 REPRESENTATIVE SPECTRAL RADIANCES OF VARIOUS SUNLIT SCENES  
Includes effect of atmospheric attenuation at an assumed sun elevation of  $45^\circ$ .  
Surface elevations are sea level unless otherwise specified, and all are assumed  
normal to the sun direction, i.e., radiances shown are expected maxima.





On the other hand, it is immediately apparent how easy it is for snow radiances in the two visible bands (4 and 5 at the left of each graph) to fall to less than half or a third of its maximum value (remembering the cosine incidence law) and thus be impossible to separate from nearby sunlit rocks and soil by single-band radiance thresholding. A particularly attractive characteristic of the groups shown here is that if the band 7/band 5 radiance ratio is less than about 0.6, the sample can be classified unambiguously as snow.

This rule will, of course, be modified whenever individual scanner resolution cells, approximately one acre in size, must average over two or more scene constituents. Also, the list of competing categories is far from complete. Nevertheless, our initial experiments using both the digital tapes and the photographic transparencies indicate that the band 7/band 5 radiance ratio alone is a very powerful snow classifier (see Figure 14). Used in combination with one or more other criteria, it gives promise of being completely adequate for objective snow surveys. Note that when the snow is wet, it is even easier to distinguish from competing spectral signatures.

Since the band 7/band 5 radiance ratio appears to be a particularly powerful classifier, it may be adequate for snow measurement without resorting to more elaborate algorithms. Multispectral analysis need not necessarily be performed entirely by digital computer; analog or hybrid techniques may provide adequate accuracy at reduced cost.

## 2. Water

Water areas usually can be extracted for measurement rather easily by minimum-radiance thresholding in MSS band 7. However, numerous occasions are encountered where local ground haze or thin high cirrus clouds add enough veiling background fill light to raise the

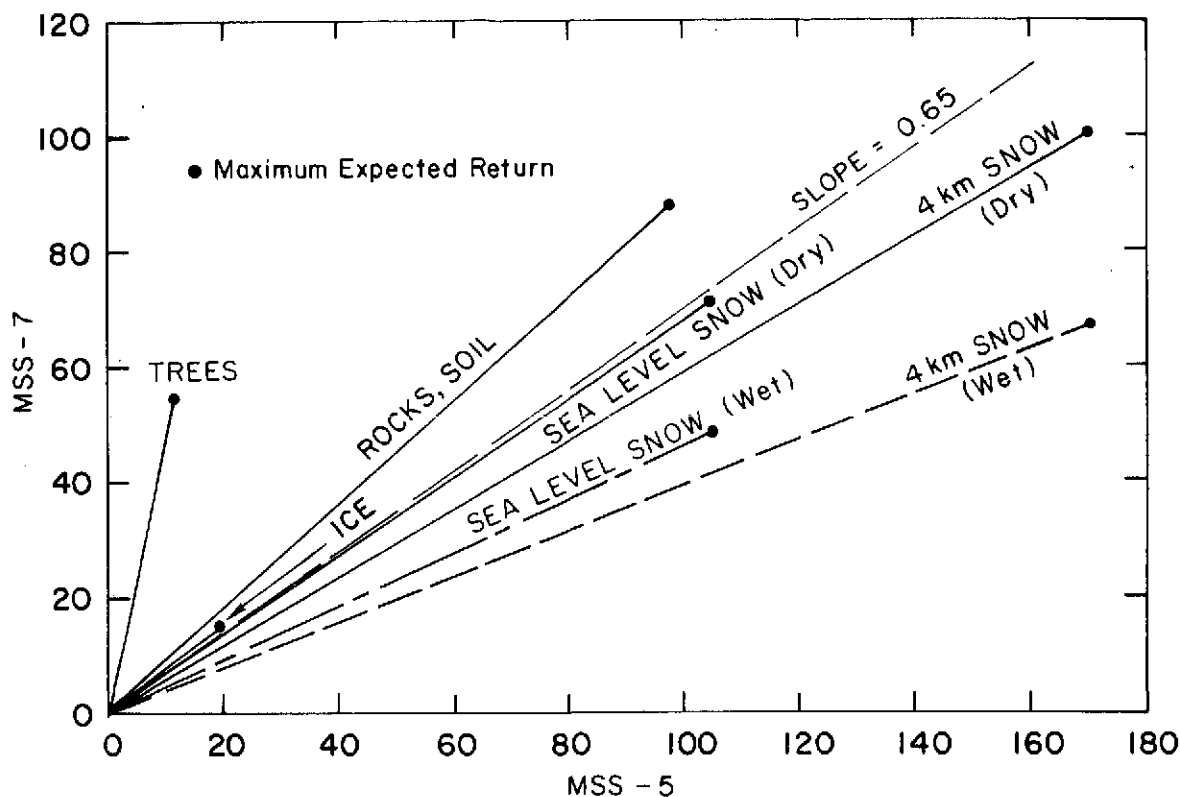


FIGURE 14 RADIANCE RATIO (MSS-7/MSS-5) OF VARIOUS SURFACES

apparent radiance of clear water by one or more gray steps, or up into the region more normally representative of macadam, moist earth, or other land features. On the other hand, the reduced atmospheric scattering in band 7 leads to deep shadows, not only near steep hillsides but sometimes also from nearly invisible high clouds and contrails. If, in addition, the shadow falls on moist earth or other areas of low IR reflectance, the region can easily be misclassified as water.

A practical problem occasionally arises when cloud-free portions of a large water body of interest are imaged partly in one ERTS frame and partly in a neighboring frame, or in the same frame of a different cycle. While the data housekeeping required is certainly tractable, it is time-consuming, and the case is indicative of a class of mosaicking-type considerations which can lead to significant errors in estimates of processing time for volume work.

### 3. Vegetation

Studies of the distribution of vegetation were always made on a bispectral basis. In this work, an annoying problem resulted from the cycle-to-cycle variations in the shape of the waveforms read from the radiance calibration step tablets, because of variations in photographic processing. While controls are available in the ESIAC vidicon camera for altering the amplitude transfer characteristic, neither the range nor the convenience of these controls was conducive to custom tailoring for each frame. Consequently, the usual set-up procedure entailed normalizing the camera output level at two gray levels, typically for steps two and eight (14% and 56% of full scale response, respectively).

While this normalization of gray scale was adequate for normal picture viewing (image space displays) and even for making quantitative measurements from the color space display for any single date, it was disturbing, while viewing the color space display in time lapse, to have the calibration ticks on the coordinate axes constantly shifting. These shifts also meant that the level-decision circuits and ratioing controls needed to be adjusted for each date even to maintain the same classification criteria. It was annoying not to be able to make rapid comparisons of the effect of an adjustment on adjacent frames or on an entire time-lapse sequence. If any significant volume of this type of work is contemplated, it would be highly desirable to provide circuitry and adjustment to permit linearizing and normalizing the gray scale response as read from film before recording in the system. When data are entered from tape, the problem is not present.

### 4. Measurement Error (Snow)

The problem of determining "accuracy" in theme measurements still remains, since little or no "ground truth" data were available. Some effort was made to assess "error" using our measurements of snow

coverage. These measurements resulted from using the single-band thresholding technique to measure snow areas. We now recognize three main types of measurement error:

Type	Definition
1. Accuracy Error (Absolute or Relative)	Departure of our measurement from the "true" value. ("True" value may or may not be known.)
2. Precision Error (Absolute or Relative)	RMS departure of individual measurements from the average of many tries
(a) short-term, single operator	
(b) short-term, multiple operator	
(c) long-term, single operator	
(d) long-term, multiple operator	
3. Differential Accuracy (Absolute or Relative)	RMS variance in date-to-date change in area

In all cases, we lump together both human error and equipment errors. At the moment, there are insufficient data to document the magnitudes of the standard errors of these various measures. The "Estimate Spreads" quoted in Section IV-A (Meier) and shown in graphs in Figure 16 of that Section do not fit any of these categories precisely, but are most closely related to category 1 (accuracy), since these have been attempts at estimating possible departure from ground truth in the absence of any real ground truth data. Additionally, however, large Estimate Spreads imply relatively poor precision, particularly long term and multiple operator precision, because the operators are confused about the location of the snow line. While time was not taken to make truly independent measurement by several operators, there is little reason to expect that such results would differ significantly from those previously obtained.

The central point is that whenever a procedure used in making the snow measurements is dependent upon the analyst's ability to detect

snow, the subsequent measurement is influenced by scene illumination and snow coverage patterns. In fact, the process of setting the radiance threshold to produce a Best Visual Estimate match to a tone-scale image can be quite sensitive--an almost imperceptible variation in the setting of the threshold can produce a significant area change. For example, in a scene where deep shadowing is apparent and where an attempt is made to match only the bright snow, the radiance threshold can be varied in such a manner that the resultant area of snow coverage can vary from the original Best Visual Estimate by as much as 15% without any marked visual difference in the slicing pattern. Attempting to reach down into the shadows to include the less bright patches can increase the area coverage by a factor of two. Based on the experience to date, the absolute snow area values arrived at solely by single-band radiance thresholding are subject to a bias that may deviate from the "true" snow covered area by perhaps as much as 25-50% of the reading.

Several suggestions can be offered which might reduce the variance in subjective evaluations:

- Study small-scale contour maps showing topography within the individual basins and historical weather patterns in the area before the measurements are made.
- Since the longer error bars always occur on the high side of the BVE count--that is, when the operator is striving to include as much low radiance snow as possible--it might well be more precise to measure only the bright snow, and then apply some form of shadow factor to account for low brightness snow undoubtedly present but not above the decision threshold. These shadow factors could be derived for specific basins by empirical measurements or through computer processing of digitized topo maps.
- The absolute spread errors might be reduced, by some as yet unknown amount, by measuring very small areas at a time, e.g., individual ridges and valleys. However, by any scheme proposed thus far, this requires a large amount of time and subjective skill.

Snow measurements need to be made through multispectral analysis rather than single-band thresholding if high accuracy is required--as has been previously mentioned.

#### D. Potential Techniques or Methods

As discussed in Section III-A, additions and modifications were made to the ESIAC during the course of this project until the available functions appeared well-matched to the needs of at least one cross-section of earth resource investigators.

Inevitably, however, a "wish list" accumulated, and it seems worthwhile at this point to discuss briefly some of the major items on that list.

##### 1. Improve Data Recording Capability

In operating the system, the rate of progress was often paced by an annoying compromise between forging ahead without breaking a train of thought and halting to document results or details of the procedure being used. It is easy to envision the help that additional machine control and more automatic data recording could provide, but these visions must be balanced by the realities of the additional costs involved. The required documentation takes at least five forms:

- (a) Alphanumeric records of frame numbers, dates, times, storage locations, scale factors, control settings, and other "housekeeping" data.
- (b) Hard copy of two-dimensional line graphs, e.g., radiance profiles.
- (c) Hard copy of two-dimensional binary maps.
- (d) Hard copy of two-dimensional tone-scale images (both monochrome and color).
- (e) Animated sequences of b, c, and d above (either movies or videotape).

The technology for achieving rapid access to quality hard copy recording of tone-scale imagery is barely with us, and one pays dearly for what is available. Fortunately, the relatively large image storage capability of the ESIAC relieves some of the pressure for "on line" hard copy generation, since the displays can be later recalled from memory and photographed. The alphanumeric housekeeping details, on the other hand, tend to be lost forever if not taken care of immediately, and there is no cost advantage in delaying the chore. Thus it seems clear that the next step upward in hardware development should be to expedite the handling of alphanumeric data (item a above).

Whether the main image storage is analog, as in the present ESIAC, or digital (see discussion in Section III-E), the additional storage capacity to carry along extensive documentation in binary form is relatively trivial. Each of the 25 unused lines during the TV vertical retrace interval could easily store 10 to 20 characters of data in binary form. These either could be read out through a teletype or other printer or could be run through a video character generator and displayed on the TV screen for viewing or photography.

## 2. Improve the System Radiometric Control

The preparation of binary thematic masks based on multispectral decisions made from photo-transparency records could be expedited and improved in accuracy by exercising more complete control of the video amplitude transfer characteristic before recording onto the disc memory. While the vidicon camera used in the present equipment is fitted with adjustable "gamma" controls, neither the range nor the operating convenience of these controls permitted complete compensation for the batch-to-batch variations that were encountered in photo processing. Operation from the digital tapes would, of course, circumvent this problem, but the present performance of the more convenient and less expensive

photo products is already so good that it seems wasteful not to try a little harder to further improve their utility. Rapid normalization of the image amplitude transfer characteristics so that "X" percent of full scale radiance for the ERTS sensor always corresponded to "X" percent of full scale in video voltage level appears technically feasible and would considerably simplify adjustment and documentation of controls for performing radiance thresholding and ratioing operations.

### 3. Consider Separate Input Record for IR/Visible Ratio

It seems probable that continued research with ERTS and other multispectral imagery will increase the use of the IR/visible radiance ratio as a feature classifier. If this proves true, it may be worthwhile to consider seriously the possibility of having the data archiving facility generate and make available to nondigital users a photographically recorded ratio image in addition to the conventional individual band images. This would be analogous to the color television practice of handling luminance and chrominance separately and would reduce the requirement for scanning-type analyzers such as the ESIAC to maintain exact image registration in order to obtain accurate ratios on a pixel-by-pixel basis. It is recommended that the potential benefits and problems of such an approach be given further thought.

### E. Cost Effectiveness

A major objective of the program has been to gather information upon which to base cost estimates for providing interactive time-lapse data analysis equipment for future research or operational applications.

To assist in this evaluation, Table 2 was prepared to arrive at an approximate ranking of capability versus system cost and complexity. As with any such general classification, specific exception can be easily pointed out, but the general picture is apparent. The ESIAC is in the



Table 2

SYSTEM/CAPABILITY MATRIX

Ranking: 3 = excellent performance  
2 = fair performance, approximate quantitative results  
1 = limited capability  
(blank) = no capability

Capability	System (approximate cost in thousands of dollars)					
	Direct Viewing (incl. planimeter, color, stereoscope, grid overlays) ( $\leq 1$ )	Zoom Transfer Scope (5)	Additive Color Viewer (incl. brightness measuring probe) (10-15)	Electronic Density Slicer (10-20)	ESIAC (150)	Dedicated Computer-Base Digital Analysis System (250-500)
Subjective image viewing	3	3	3	2	3	1
Amplitude (radiance) measurements	1	1	2	2	2	3
Subtle feature enhancement (edge enhancement, color coding, time lapse, flicker comparisons)				2	2	1
Image comparisons (flicker, superposition, time lapse, multicolor)	1	2	1		2	1
Spectral signature analysis	1	1	1	1	2	3
Objective feature classification; thematic maps; area measurements						
Single band, amplitude-dependent				2	2	3
Multi band, amplitude + logic					2	3
Multi band, ratioing					2	3
Higher level mathematical transformations						3

cost bracket more usually associated with a service bureau or data center operation than with individual ownership. The cost must be justified partly by the ability to detect very subtle frame-to-frame changes (difficult or impossible by any other method), partly by the ability to make first-order thematic classifications based on multispectral data, and partly by the ability to rapidly achieve useful proficiency in an extremely wide gamut of analysis techniques. A measure of the budget environment familiar to the ERTS principal investigators affiliated with this project can be gained by considering that of the seven, only three currently have easy access to additive color viewers.

Particularly when it is conceded that the maintenance cost of relatively complex, special-purpose equipment such as the ESIAC is considerable, it becomes apparent that for most individual research investigators, the most practical means of access would be at a service center or at a data center. When an application becomes so well-identified that it can be considered for operational use, the volume of data flow probably will be great enough and possibly the required functions may be few enough that substantial equipment economies could be realized.

For the present, we regard the ESIAC as a design tool, to be used to tell one what to incorporate into future either special-purpose or general-purpose image analysis systems.

One way to examine the cost-effectiveness of this type of equipment is to project an hourly operating cost or rental rate (based on equipment amortization plus maintenance), and then to estimate the time a researcher would be willing to spend with the equipment or the hourly data throughput which might be expected in an operational mode. On this basis, the present ESIAC costs out at about \$35 per hour for the equipment alone or about \$55 per hour when one includes the technical operating assistance that is often required.

In our experience, this order of time cost is about as much as an individual researcher will consider for an interactive system. It is considerably more than he would like to pay, when much of the clock time is, or should be, occupied merely by thinking. Of the possible ways of reducing this operating cost, the following options have been suggested:

- (a) Large volume equipment manufacture.
- (b) Multiple terminals with time-sharing of more expensive equipment items.
- (c) Less expensive equipment design.
- (d) Further simplification of controls to eliminate the "co-pilot" operator.

The first option is dependent upon success of the other three or upon an important new application area, not yet defined. It offers no short-term solution.

With respect to option d, our experiments thus far suggest that elimination of the "co-pilot" probably is not realistic for many research applications. With so many operating options available, confidence is improved immensely when there are two people checking each other and agreeing upon subjective evaluations. Indeed, much of the value of the large-screen, multiple-display concept appears to be tutorial--effectively pooling the thinking of several observers in conference.

The remaining options (b and c) both involve equipment design considerations, the area where economies are most probable. Considering option b, multiple-access time-sharing of the main memory file and of the data entry device offers attractive opportunities for achieving economies and should be considered in any future equipment planning. At the time the ESIAC was designed, the only practical way of achieving the desired several hundred frames of rapid-access gray-scale image storage was with an analog video disc recorder, (cost = \$25-30,000). Digital storage would have cost at least an order of magnitude more.

The cost of digital storage has been dropping steadily, while the cost of high quality analog disc machines has remained relative unchanged, partly because of lower volume production. While no directly applicable digital disc storage equipment is known to these authors, it appears that relatively straightforward modifications to currently available high-density digital disc drives would not permit a digital equivalent of the present ESIAC analog disc recorder for perhaps twice to three times the price. The additional flexibility, and particularly the ability to transfer images repeatedly without degradation, would probably be worth the additional cost. This recommendation for digital storage does not necessarily imply abandonment of TV camera input from transparencies in favor of input from computer-compatible tape. That choice can and should be made independently, since conversion between analog and digital realms at video rates does not now introduce an overwhelming expense.

It seems probable that both photographic and digital input equipment will be required for most future applications. Until very major changes come about in the cost, speed, and physical volume of digital storage and manipulation, users will be reluctant to give up the convenience and simplicity of photographic media for library and data transmission purposes and for applications such as time-lapse viewing where the ultimate in accuracy is not required for each and every frame.

By implementing equipment sharing economies similar to those suggested above, and by operating several stations on a fairly full schedule, it appears reasonable for a service center or data facility to provide ESIAC-like data analysis facility for about \$25-50 per hour, an apparently tolerable rate for research applications. It does not appear realistic to expect a rate appreciably below that without giving up a large number of the functions currently provided in the ESIAC.

However, for single-purpose and high-volume operational applications, such specialization may be both feasible and desirable.

The equipment design suggested in the foregoing section--involving digital storage, occasional use of CCT input, and provision for interfacing to other digital equipment--may lead the reader to conclude that what is being described is a scaled-down version of one of the computer-based data classification systems currently available at rental rates of \$100-200 per hour, rather than a scaled-up version of the ESIAC. We believe that this is not the case. While our knowledge of all-out digital systems is modest, what we do know tends to confirm the reservations expressed by many serious investigators that they are not yet ready to cope with such a large system. Particularly to those individuals who have familiarity with spooling film, zoom lenses, map overlays, and simple graphic editing procedures, the human-engineered controls of the ESIAC appear natural and are quickly taken in stride, while the structured commands required to communicate with the usual "interactive" computer require considerably more mental agility and are frustratingly slow. This is not to say that the larger systems could not be engineered to handle more naturally, but merely that since it has not yet been done, such changes would, in the normal course of events, add to an already discouraging operating cost, not detract from it. In short, the ESIAC was designed for a class of users who need more than simple viewing equipment, but who are not mentally or financially ready for a more sophisticated system.

An ESIAC-like system could well provide the needed stepping stone to prepare users for more efficient utilization of numerical image processing on larger systems.

## F. Recommendations

1. It is recommended that animated image analysis equipment possessing the general characteristics of the ESIAC be made available to earth-resource personnel concerned with monitoring dynamic phenomena or otherwise interested in fully exploiting the repetitive nature of ERTS-type imagery.

Availability of the analysis facility to the resource manager or scientific investigator on an interactive basis is considered essential for study and planning purposes. To provide the required amount of equipment and support services at a tolerable cost will probably require a service-center type of operation, with a number of display/analysis stations sharing as much as possible in the use of common scanning, storage, and picture processing hardware.

2. The methods of dynamic, quantitative image analysis made possible by the ESIAC appear particularly well-suited to assisting the monitoring of snow and ice in remote and rugged terrain. In view of the considerable economic importance of such work, it is recommended that research in this area be expanded.

#### IV DATA PROCESSING FOR USGS INVESTIGATORS

The major contributions of SRI support to the principal investigators included:

- The development of the Electronic Satellite Image Analysis Console (ESIAC) for analysis of ERTS information.
- Advisory consultation to the participating investigators in the Program in Dynamic Hydrology regarding information retrieval peculiar to their investigation needs.
- The production of data products in compliance with specific instructions of the participating investigators.

Naturally, advisory consultation between SRI and the investigator played a large role at the onset of the investigation--particularly in reaching a balance between what investigators wanted from ERTS imagery and what could be successfully extracted and objectively measured from the imagery that was of significant value to the objectives of the individual USGS investigators. However, such consultation was carried through the life of the contract. Fortunately, all of the participating investigators were able to come to SRI one or more times for "hands on" working sessions regarding data handling, processing, and documentation capabilities of the ESIAC relevant to their particular requirements. Data reduction and documentation requirements were established during these visits regarding routine data handling for the ERTS images to be processed for each of the investigators under the terms of the existing contract. In fact, the most apparent progress in information retrieval was made when the individual principal investigators worked interactively with ESIAC.

Some of the products generated on the ESIAC and provided to the USGS investigators in the Dynamic Hydrology program, have been as follows:

- (1) Animated or static scene imagery (monochrome or color) for
  - (a) Feature delineation
  - (b) Scene overlays
- (2) Binary overlay of themes for
  - (a) Area measurements
  - (b) Feature enhancement
- (3) Radiometric analysis through
  - (a) Profiles of single band radiance versus distance
  - (b) Displays showing two-band scatter diagram of entire scene or selected segments thereof.

In addition, ESIAC was also used to advantage in preparing photographic products (movies, overlays, and hard copy) for reports, presentations, and more leisurely study.

Selected examples of these services and products are included in the following description of the research undertaken for the participating principal investigators in the USGS Program in Dynamic Hydrology.

A. Snow Dynamics Dr. M. F. Meier (INO 45), USGS, WRD,  
Tacoma, Washington

1. Tasks

- a. Measure snow cover for selected basins in the North Cascade region plus Mt. Rainier through an extended period.
- b. Determine the accuracy with which snow can be measured, considering the effects of seasonal changes and surface conditions upon snow appearance, and spectral response.
- c. Use ESIAC to study glaciers, i.e., their shape and dimension, changes in size (especially edges), terminal moraines, glacial surges, and snow cover. Both advantages and disadvantages of using the electronic system (ESIAC) for these purposes are to be delineated.



- d. Determine reflectance signatures of dry and wet snow.
- e. Make a meteorological analysis attending changes in snow cover over the Olympic Peninsula during a selected period.

## 2. Services and Products

The initial areal snow measurements were made for Mt. Rainier using the data for cycles 0 through 11. Following this, snow cover measurements were made for basin 1825, 1755, 1434 + 1420 and 1330 for cycles 0, 2, 4, and 6 (see Figure 15 and Table 3). The aforementioned basin areas are of very rugged terrain and present formidable challenges to the measurement of snow cover. Special problems include the changing spectral responses of snow during changing seasons with underlying terrain (rock or forest coverage) and varying degrees of shadowing. A number of measurement techniques were investigated, but the most extensively investigated approach was to evaluate the amount of snow via simple radiance thresholding in a single spectral band.

To estimate snow coverage for any particular cycle and basin, the procedure was to generate a binary mask of areas with a technique termed "radiance-above-threshold" using the MSS-5 image. The threshold was varied to obtain the Best Visual Estimate (BVE) of the binary mask to the areas subjectively determined to be snow in the full tone scale band 5 image. All measurements were made by performing the thresholding operation on the band 5 signal. However as an interpretative aid to the operator, a two-color image (usually bands 5 and 6) was entered for each basin for a summer or fall date when the forested regions showed up most clearly. All images were carefully registered to each other and to the basin outline. Thus time-lapse comparisons were also possible, and provided additional help in estimating the location of the snow line, particularly through depiction of smoothly changing shadow effects.

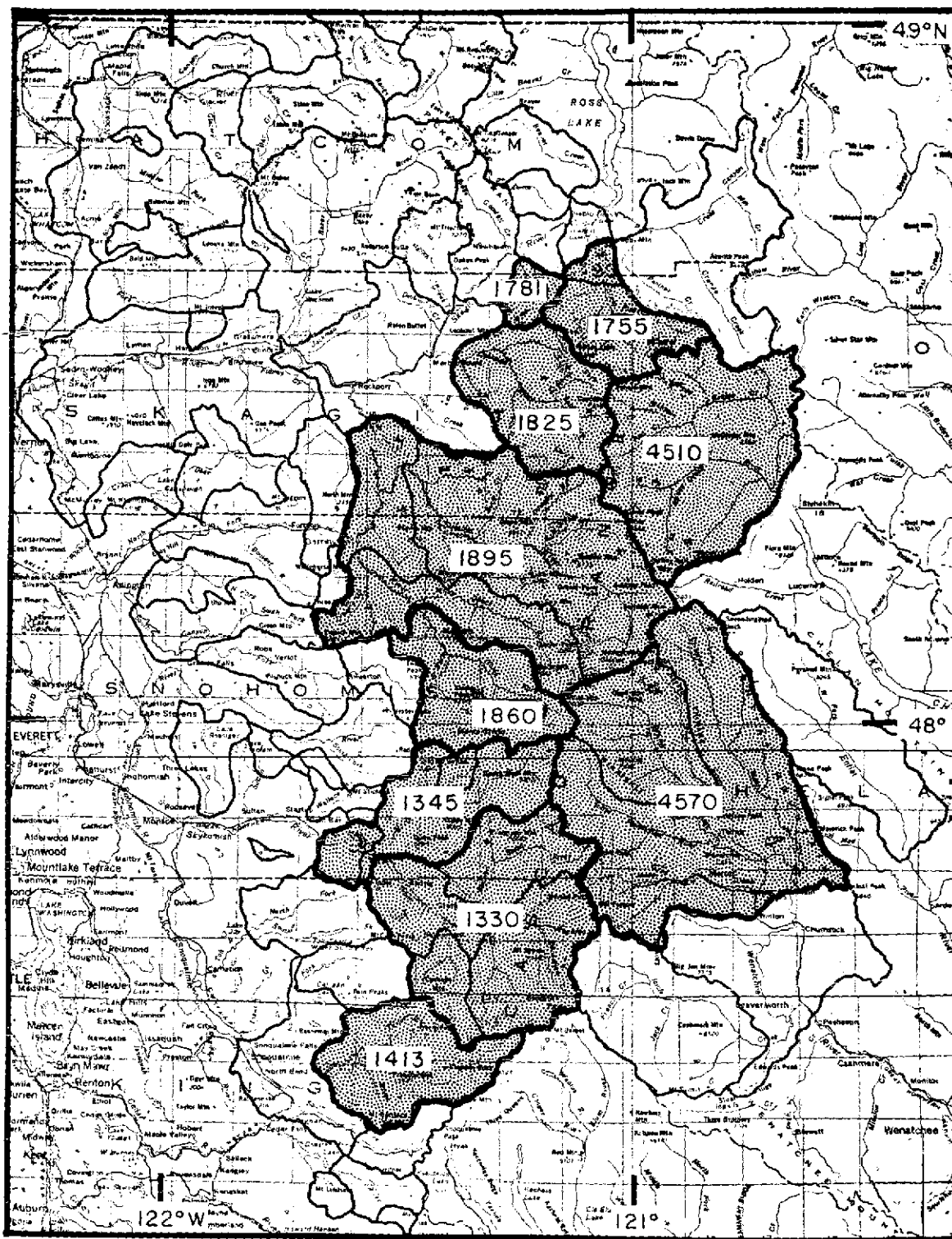


FIGURE 15 BASIN LOCATIONS IN CASCADE MOUNTAINS, WASHINGTON

Table 3 List of Cycle Numbers for Which One or More Basins Could be Evaluated

Date	Cycle No.	Basin										Total Basins	
		1330	1345	1413	1755	1781	1825	1860	1895	4510	4570		
1972													
29 July	0	x	x	x	x	x	x	x	x	x	x	10	
16 Aug	1	-----				N/A	-----					0	
2 Sept	2	x	x	x	x	x	x	x	x	x	x	10	
20 Sept	3	-----				Area	Cloudy	-----					0
8 Oct	4	x	x	x	x	x	x	x	x	x	x	10	
26 Oct	5	- cloudy	-----			N/A	-----	cloudy	-----	N/A	- cloudy	0	
14 Nov	6	x	x	x	-	cloudy	-	x	x	cloudy	N/A	5	
12 Dec	7	-----				Area	Cloudy	-----					0
20 Dec	8	-----				N/A	-----					0	
1973													
6 Jan	9	x	x	x	----	N/A	----	x	----	N/A	x	5	
25 Jan	10	---	cloudy	---	----	N/A	----	cloudy	---	N/A	cloudy	0	
12 Feb	11	---	cloudy	---	x	cloudy	x	---	cloudy	N/A	cloudy	2	
2 Mar	12	-----				N/A	-----					0	
20 Mar	13	-----				N/A	-----					0	
7 Apr	14	x	x	x	x	x	x	x	x	----	N/A	8	
25 Apr	15	x	x	x	x	cloudy	x	x	x	----	N/A	7	
12 May	16	-----N/A-----			x	x	x	N/A	x	x	N/A	5	
30 May	17	x	x	x	x	x	x	x	x	x	x	10	
18 Jun	18	---	cloudy	---	----	N/A	----	cloudy	---	N/A	----	0	
6 July	19	-----				N/A	-----					0	
24 July	20	-----				N/A	-----					0	
11 Aug	21	x	cloudy	x	x	x	x	x	x	-	N/A	7	
29 Aug	22	-	N/A	-	-		cloudy		-	-	N/A	0	
12 Sept	23	x	x	x	x	x	x	x	x	x	x	10	
8 Oct	24	x	-----		N/A	-----	x	N/A	x	N/A	x	3	
Total Cycles		11	9	10	10	8	10	10	11	6	7		

\*  
x = measured  
N/A = No Data

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The major portion of time required for the entire procedure just described is concerned with the mechanics of setting up the display and with the operator's becoming familiar with the scene. Since the time required for making the actual area measurement was relatively small (a minute or two), it became feasible to make multiple readings to investigate the sensitivity of the area results to small changes in subjective attitude and procedure. This was very instructive and provided an appreciation for the care that must be taken to prevent making over-optimistic estimates of accuracy and precision. Procedurally, having derived the Best Visual Estimate, the analyst then raises the radiance threshold until he has reached a relatively high confidence that the true snow coverage is greater than that corresponding to this new threshold. In so doing, the binary mask shrinks to cover only the brighter elements. Conversely, the operator then lowers the threshold in order to encompass the less bright elements that may or may not be snow until he has reached an equal confidence (admittedly subjective) that the true snow coverage is less than this lower threshold coverage. This range from "minimal amount" to "maximal amount" about the Best Visual Estimate has been termed the "estimation spread" when the confidence limits are taken at about 85%. The Best Visual Estimates, together with the 85% confidence estimation spreads, constitute the bulk of the measurements taken in this work task. Occasionally, values were recorded for the still wider estimation spread obtained when the operator attempted to indicate his estimate of his maximum possible uncertainty, i.e., his approximately 99% confidence limits. Figure 16 illustrates such curves for the Mt. Rainier scene on 11 February 1973. The abscissa is in gray-scale steps (step 0 = zero radiance). The ordinate is area (in square kilometers) above threshold. In the example presented, it is obvious from the slope of the curve that the change in area is smallest in gray-scale steps 6, 7, and 8 and increases as one progresses to gray-scale steps below 6. This is true both for MSS

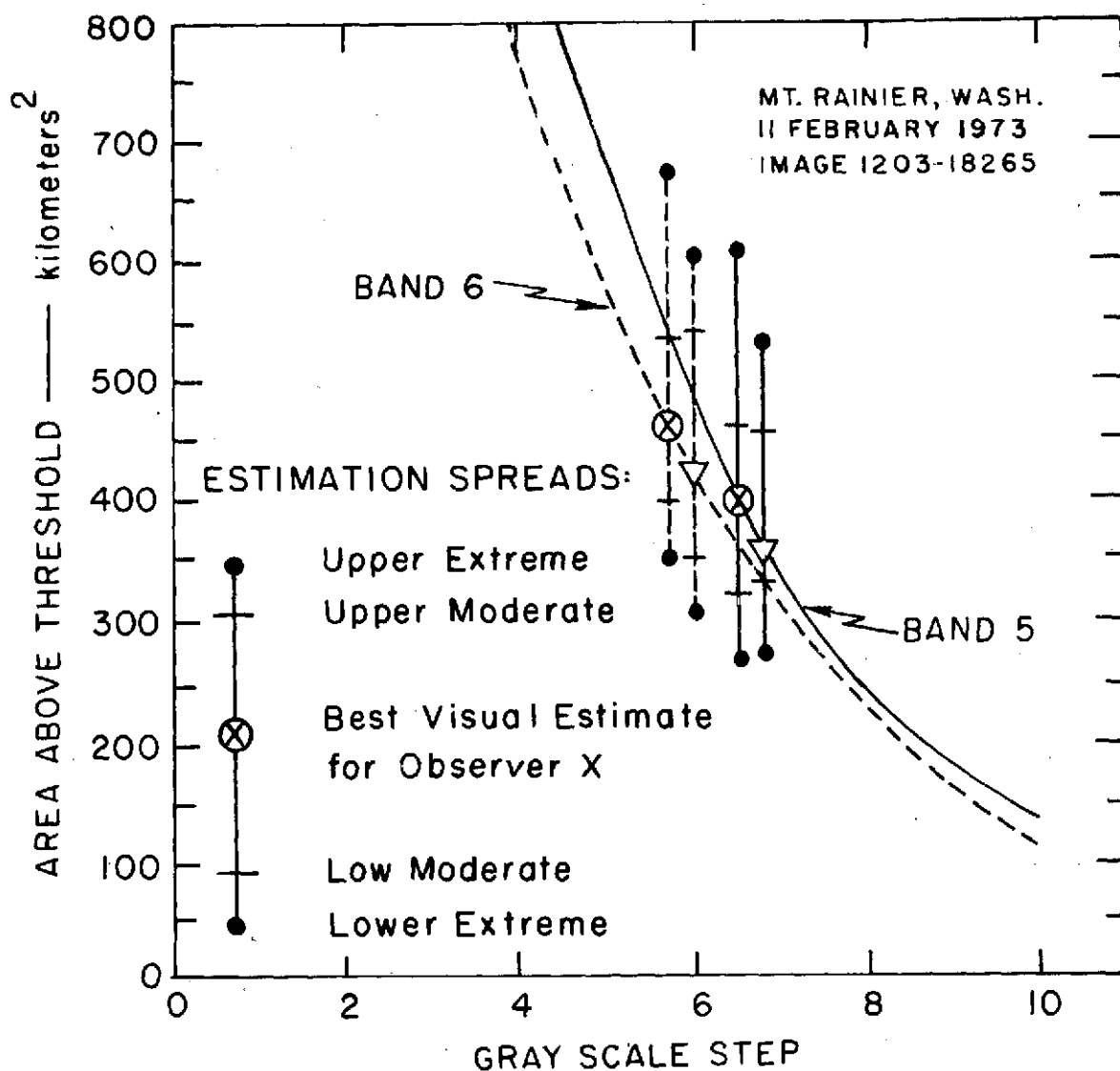


FIGURE 16 AREA VERSUS GRAY STEP

Example of typical functional dependence. Plotted points represent threshold settings preferred by two different operators. Tolerance bars indicate operator estimates of possible departures from ground truth.

band 5 and band 6. Consequently, the procedure is increasingly sensitive to the "slicing level" used as one attempt to include more of the low radiance snow.

The curves themselves were derived purely objectively, by measuring digital pixel count versus radiance threshold setting. Best Visual Estimate and estimation spreads for both 85% and 99% confidence are shown for subjective settings reached independently by two different operators.

It is encouraging that this procedure yields Best Visual Estimates and variances that are fairly consistent. In this example, in both bands 5 and 6 the distance to the lower extremes from the Best Visual Estimate is about half of the departure to the upper extremes. This has been true, generally, for all the data evaluated to date.

The slopes of the curves (which express area above thresholds for gray-scale steps) vary with season (because of changes in sun angle and amount of snow present). The curves for Mt. Rainier in Figure 17 illustrate these variations. However, to date, about 75% of the best visual estimates on band 5 fell between gray steps 5.5 to 6.5, and all estimates were between the range 4.8 - 6.8. For the 9 cycles measured of this same mountain, the inter-operator spreads ranged from  $\pm 2.5\%$  to  $\pm 16.7\%$  of the average reading.

Figure 18 is an array of small reproductions of the binary snow masks showing the distribution of snow over a small drainage basin in the North Cascade range basin during a full year. The measured areas are shown by each mask, and the gaps in the coverage because of cloud cover are obvious by the omissions. When the coverage is small, the snow patches tend to be grouped in a small area, reducing the effect of spatial differences and reducing the number of compromises which must be made. When the coverage is greater, the spatial patterns are more likely to be dendritic, and very small changes in the threshold can rapidly change the fatness of the branches. To further illustrate the need for subjective care that had to be exercised, Figure 19 shows

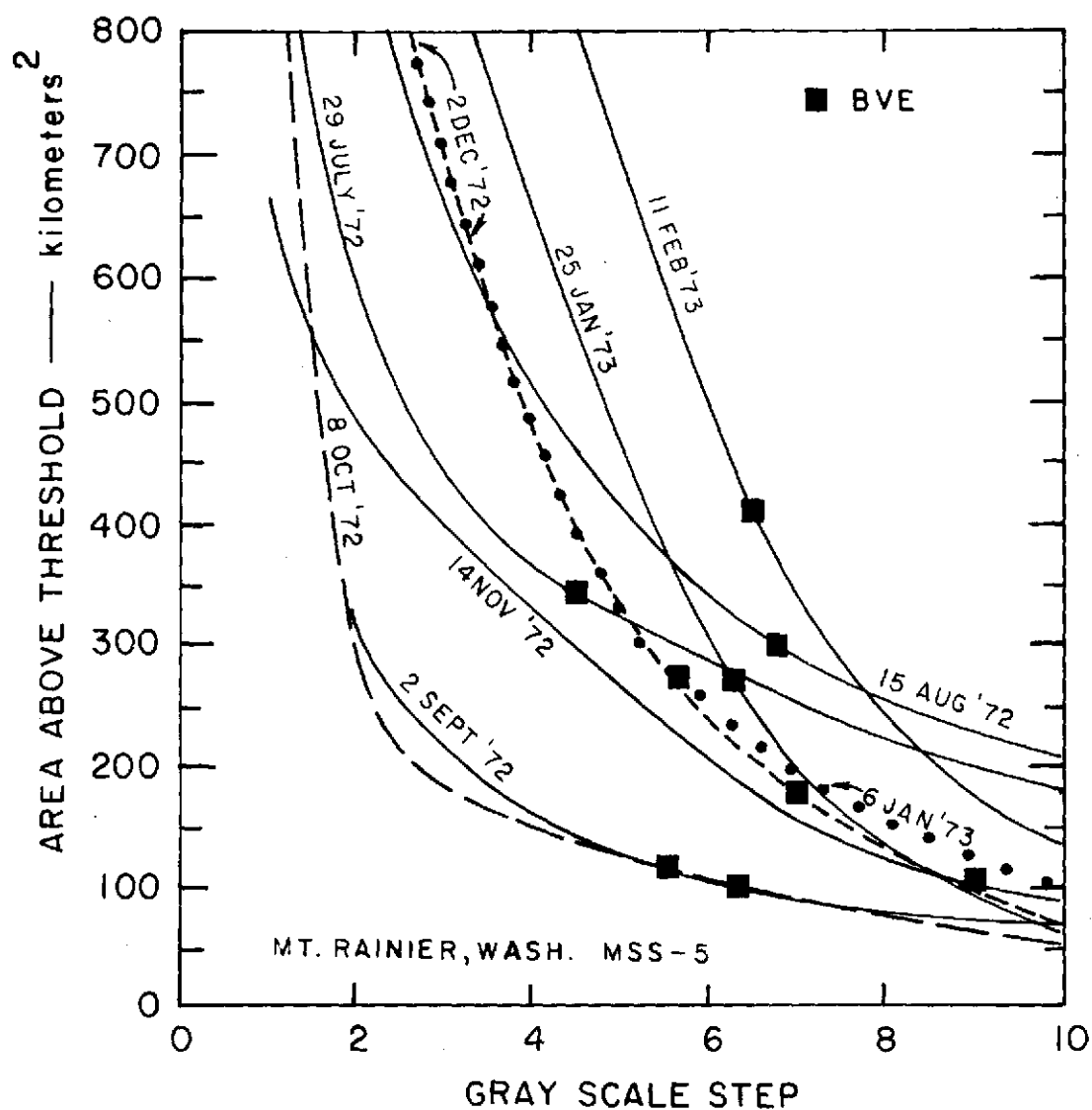


FIGURE 17 AREA VERSUS THRESHOLD LEVEL FOR NINE DATES

Region counted was 45 km diameter circle centered on Mt. Rainier. Plotted points are Best Visual Estimate (BVE) averages for two operators.

two masks sliced at slightly different radiance values. While the masks appear very similar, the areas of the top two, for example, actually differ by 15%. Basin areas and snow coverage (for cycles available between 29 July 1972, cycle 0 and October 8, 1973, cycle 24) were evaluated via the just described single-band radiance thresholding

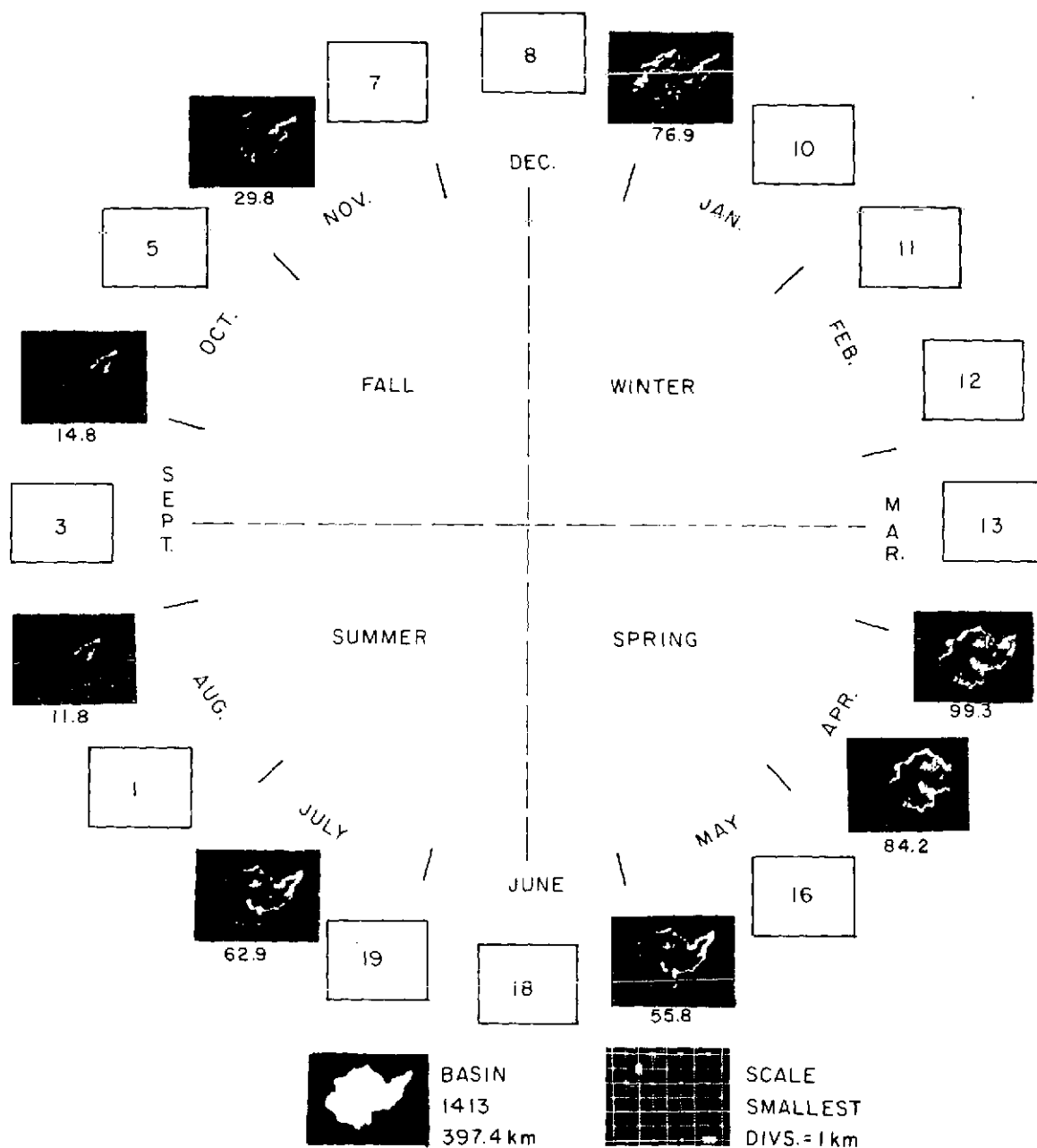
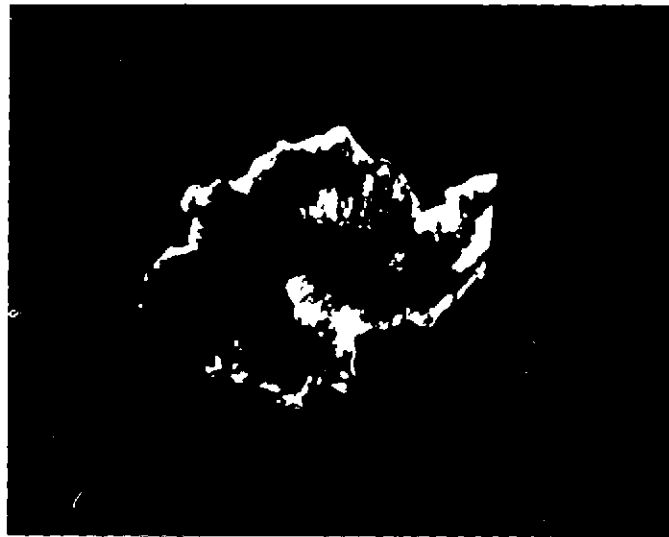


FIGURE 18 BINARY MASKS OF MEASURED SNOW WITHIN BASIN 1413, NORTH CASCADES, WASHINGTON

Basin location indicated in Figure 15. Data shown for all available cloud-free images within the period 29 July 1972 through 30 May 1973. Radiance threshold for MSS-5 set for Best Visual Estimate (BVE). Numbers below masks give snow area in km<sup>2</sup>.





AREA 99.3 sq km (Best Visual Estimate, BVE)



AREA 114.2 sq km (1.15 BVE)

25 km

FIGURE 19 SELECTED SNOW COVER MASKS FOR  
7 APRIL 1973, BASIN 1413

Note the care requirement to detect an  
area change of 15%.

procedure for basins 1755, 1781, 1825, 1895, 4510, 1345, 1330, 4570, and 1414 (see Figure 15 and Table 2).

In an attempt to reduce BVE variances, other measurement techniques were tried. One such approach was the date-to-date differencing of snow cover. An example of this technique is illustrated in Figure 20 (panels a to e) for Mt. Rainier, Washington. Panel a shows snow cover near its yearly minimum. Panel b shows the addition of new snow. Panel c is a TV display of the result of subtracting the video signal for panel a from the video signal for panel b. Those areas where there has been no significant radiance change cancel to a mid-gray appearance (regardless of whether the original scene content had been bright and dark). Anything whiter than the mid-gray level in panel c is interpreted as being new snow (or cloud). Conversely, the dark-gray-to-black regions indicate regions where the radiance had decreased significantly during the 37 day period. Panels d and e show binary masks derived by "slicing" (thresholding) the difference signal of panel c. The white or "true" regions of each mask is then measured separately by a digital pixel counter.

An additional approach considered used the concept of estimating snowpack on Mt. Rainier by assigning an Equivalent Snow Elevation. This technique has gained some acceptance in snow hydrology and, in fact, detailed tables of area versus elevation are already available for many snow accumulation regions of practical interest. One product that was tried entailed cycling through a set of registered binary masks, each mask depicting all areas above a specified threshold elevation. The mask that provides the best visual match to the snowpack would then define the Equivalent Snow Elevation.

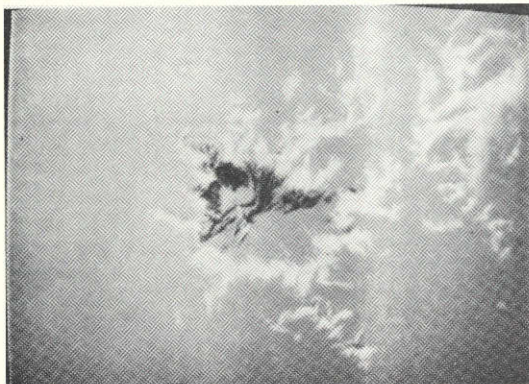
Figure 21 shows Mt. Rainier covered not by one of the aforementioned masks of area-above-given elevation, but by a conventional



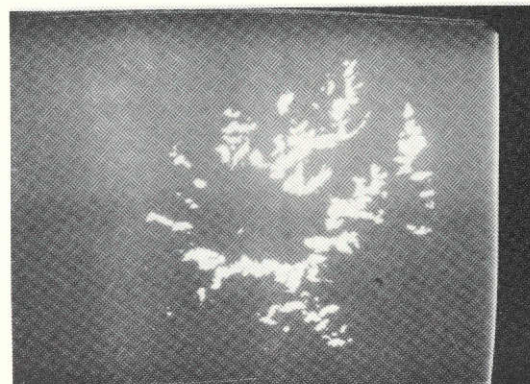
(a) MT. RAINIER, WASH. 8 OCTOBER 1972  
1077-18-260-5



(b) MT. RAINIER, WASH. 14 NOVEMBER 1972  
1114-18-322-5



(c) CONTINUOUS TONE DISPLAY OF DATE TO  
DATE IMAGE DIFFERENCING (MSS-5) 14  
NOVEMBER-8 OCTOBER 1972



(d) 14 NOVEMBER-8 OCTOBER 1972 BINARY  
MASKS OF WHITE REGIONS OF PANEL C



(e) 8 OCTOBER-14 NOVEMBER 1972 BINARY  
MASKS OF BLACK REGIONS OF PANEL C

25km

FIGURE 20 DATE-TO-DATE DIFFERENCING TECHNIQUE



contour overlay with 1,000 foot contour intervals. Snow line estimates from this type of display are possible, but are appreciably more difficult than with the dynamic method. Since no one elevation, in general, fit the snow field in all areas, it was necessary to subdivide the Mt. Rainier region into three pie-shaped sectors, match the snow line in each, evaluate each area, and then total. This evaluation has been completed for cycles 0, 2, 4, 6, 7, 14, 15, 16, 17, and 18.

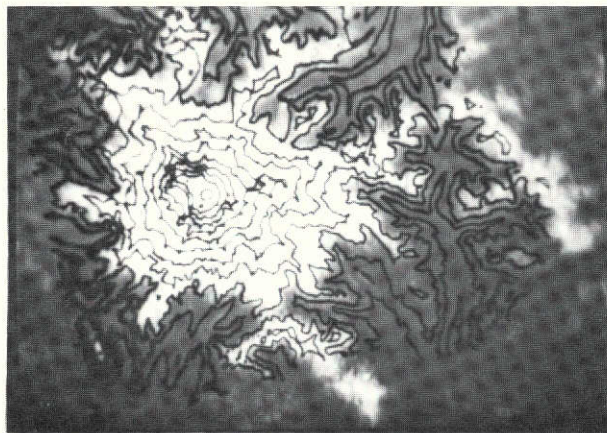


FIGURE 21    ESIAC DISPLAY SHOWING 1000-ft  
                  CONTOURS OF MT. RAINIER,  
                  WASHINGTON, ELECTRONICALLY  
                  SUPERIMPOSED ON 30-km SECTION  
                  OF ERTS IMAGE NO. 1005-18260-5  
                  FOR 29 JULY 1972 (CENTRAL  
                  CONTOUR IS 14,000 ft)

On the 8th of June, Messrs. W. Evans and S. M. Serebreny of SRI visited Dr. Meier and staff at Tacoma for discussions about many aspects of snow measurements from ERTS imagery over mountainous terrain, particularly with respect to questions of ground truth data reduction and measurement variances. Details of U2 imagery of the Mt. Rainier area were studied at SRI in color and color stereo to establish more definitive rules about how to set the slicing threshold when measuring ERTS images on the ESIAC. An analysis of the digital tapes for this area was also conducted. The conclusion expressed at that time was that attempts to obtain absolute measurements of snow extent by simple

radiance thresholding in a single spectral band appear doomed to an annoying amount of subjective variation, particularly in mountain areas in winter where local illumination levels vary widely.

Date-to-date differencing techniques appear useful in cancelling some of the systematic errors in the absolute measurements when the important parameter is the change in snow cover, but concrete figures on this differential accuracy must await more complete ground truth data.

The most promising approach to reducing the subjectivity of snow area measurements is to exploit the multispectral data contained in the ERTS imagery. For example, it is possible to perform analog ratioing of two registered single-band signals before employing the level-detection and pixel-counting circuitry. Using this procedure, the binary mask can be made to represent all picture points for which the spectral ratio exceeds some specified value, is less than the specified value, or falls between two specified values. Figure 22 is an example of this type of product. The light gray regions are areas where the response was near saturation in band 5 and thus almost certainly represented snow. The bright regions of the map indicate areas of lower radiance, and an MSS-7/MSS-5 radiance ratio of less than 0.65 (which was the snow-classifying criterion being evaluated). Some of these regions would have been missed by single-band radiance thresholding.

Other services that were provided included measurement of glacier progress and reflectance signatures of wet snow and dry snow. In addition, toward the end of the contract, a provisional analysis was made regarding the meteorological parameters that accompanied the growth of snow pack, using the Olympic Peninsula during January and February as a test site. In this analysis, such parameters as temperature, precipitation as deduced from surface observation, cloudiness, wind data, and humidity were used to correlate with the snow cover

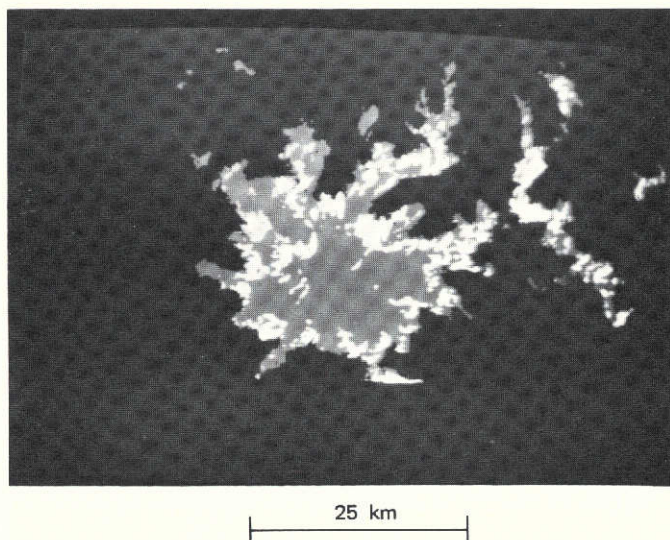
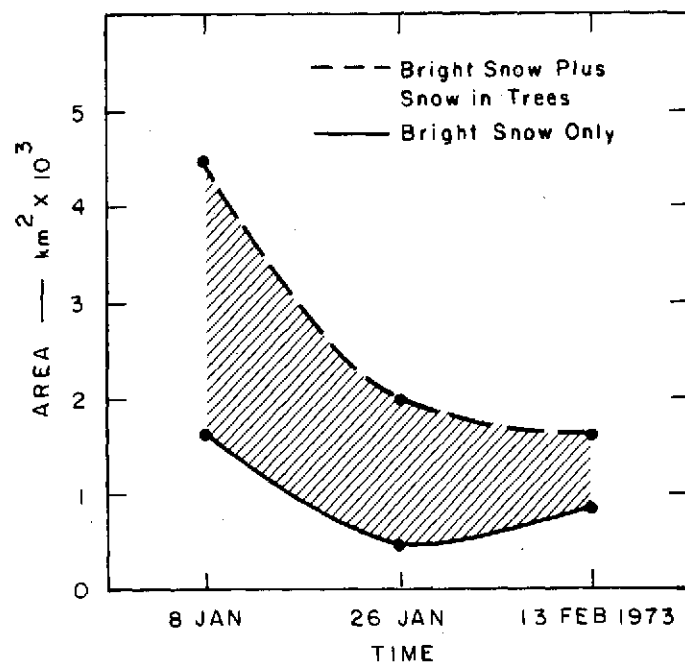


FIGURE 22 EXAMPLE OF RATIO CLASSIFICATION  
USING THE ESIAC

Two binary thematic masks are superimposed.  
The brighter one represents areas which were  
selected on the basis of two-band radiance  
ratios.

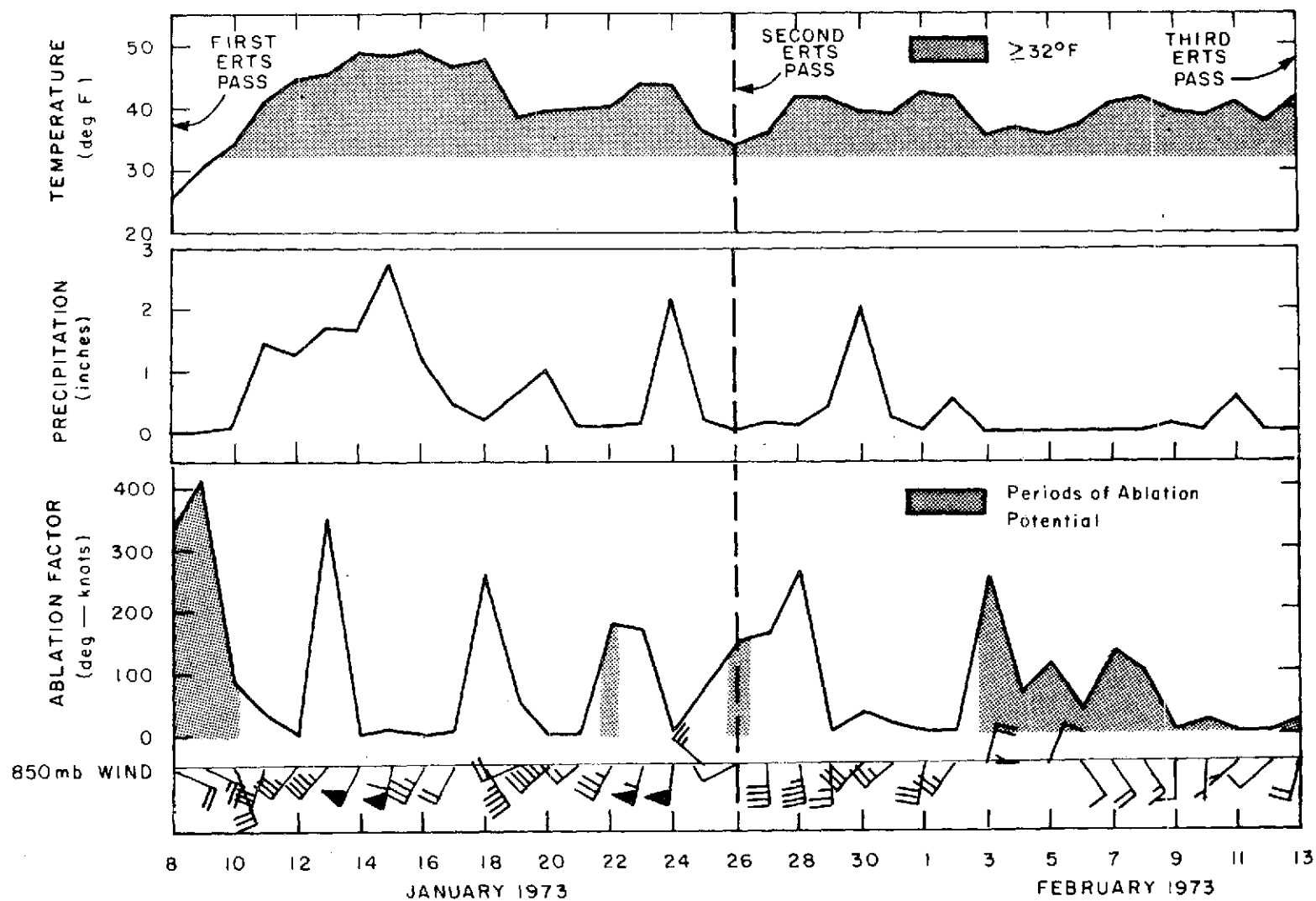
measurements. An example of the resultant analysis is given in Figure 23. The time period chosen was relatively short--only two ERTS cycles--and the results are not overwhelming, but further investigation seems warranted.

ERTS imagery (MSS-5) of the Olympic Peninsula was obtained for the three consecutive passes (8 and 26 January and 13 February). Two estimates of the area of snow cover for each day were obtained--one representing bright snow, and one estimating bright snow cover plus the estimated area encompassing snow in trees. Both estimates were obtained by brightness slicing on the MSS-5 images, but only after a preliminary analysis of the MSS-5 and MSS-7 combination. Estimate of "bright" snow cover provides a measurement that can probably be best related to other data.



(a) AREA OF SNOW COVER

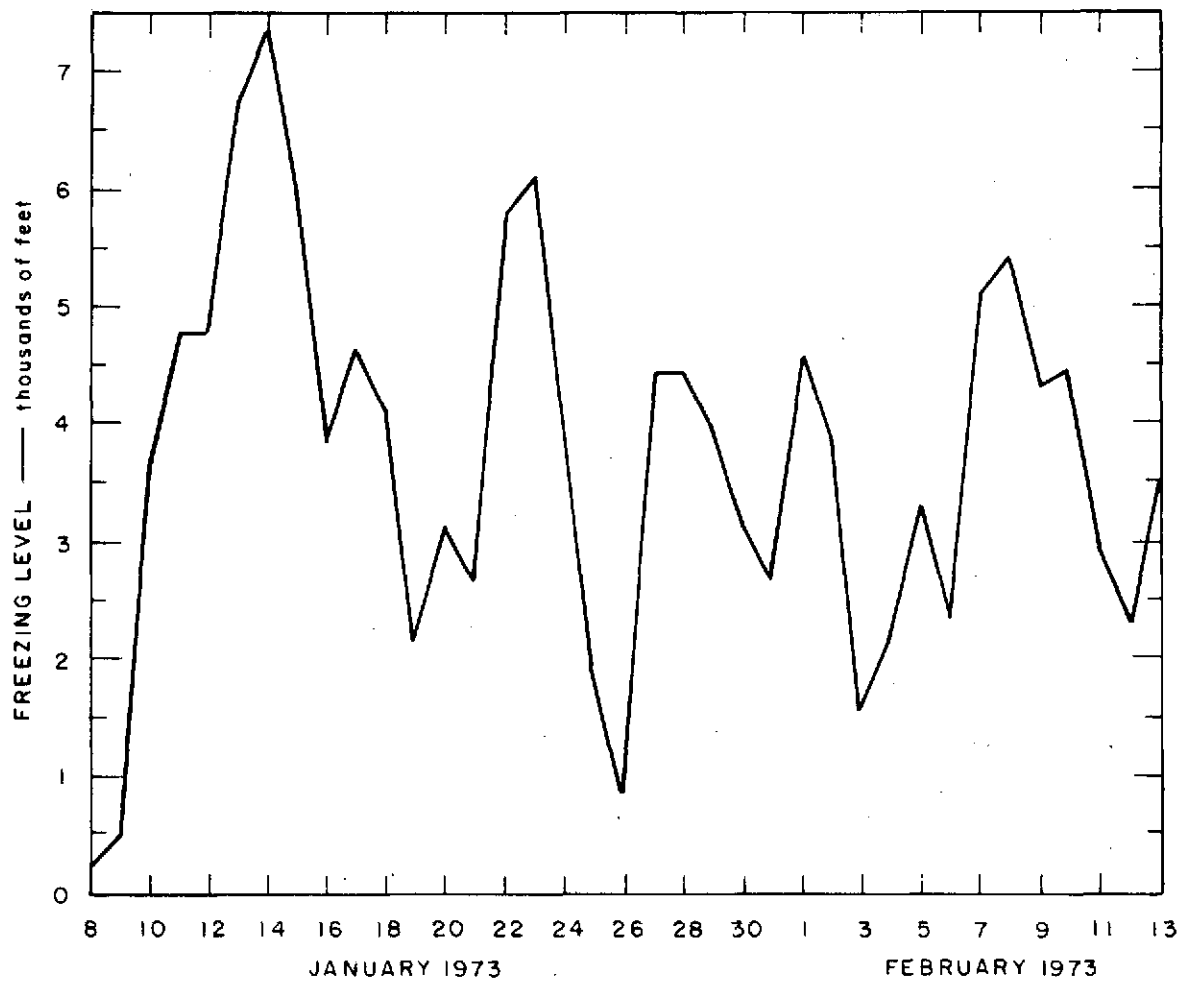
FIGURE 23 CORRELATION OF SNOW COVER WITH METEOROLOGICAL PARAMETERS



(b) OBSERVATIONAL RESULTS OVER 36 DAY PERIOD

FIGURE 23 CORRELATION OF SNOW COVER WITH METEOROLOGICAL PARAMETERS (Continued)





(c) DAILY VARIATION OF FREEZING LEVEL (AVERAGED BETWEEN 1200 AND 0000 GMT)

FIGURE 23 CORRELATION OF SNOW COVER WITH  
METEOROLOGICAL PARAMETERS (Concluded)

Binary masks were generated to represent the two snow-cover estimates for each day. The estimated snow areas (see panel a, Figure 23) show a decline through the first cycle, and then a small recovery over the 36-day period covered by the ERTS passes. Only two types of surface information were available from stations in the area: the daily maximum and minimum temperatures, and the total daily precipitation. In addition, three parameters were tabulated from the twice-per-day vertical soundings taken at one of the stations, Quillayute: 850-mb wind speed and direction, 850-mb dew point depression, and the height of the freezing level plus the surface cloud observations. These data were analyzed for general processes that influence changes in the snow pack: insolation melt, precipitation, and ablation. Panel b of Figure 23 summarizes observational results over both 18-days ERTS cycles.

The relative shaded areas of the temperature curve between successive ERTS passes indicate the relative potential for melt during each period. The precipitation curve indicates the potential for decrease or increase in snow pack during each ERTS cycle, depending on whether the precipitation occurs as relatively warm rain or as snow at snow covered elevations. As a crude measure of ablation potential, we have selected the product of the 850-mb wind speed and the 850-mb dew point depression. The ablation potential (shaded areas) is more or less limited to the periods of clear skies.

Panel c of Figure 23 illustrates the daily variation in the freezing level. It is apparent that much of the precipitation occurred under conditions with a relatively high freezing level.

B. Desert Vegetation Dr. Raymond M. Turner (IN411) USGS, WRD,  
Tucson, Arizona

1. Tasks

Map and document the area and areal changes in phreatophytes and other arid-land plant communities within four selected test sites in Arizona: Tucson, Avra Valley, Sabino Canyon, and Benson.

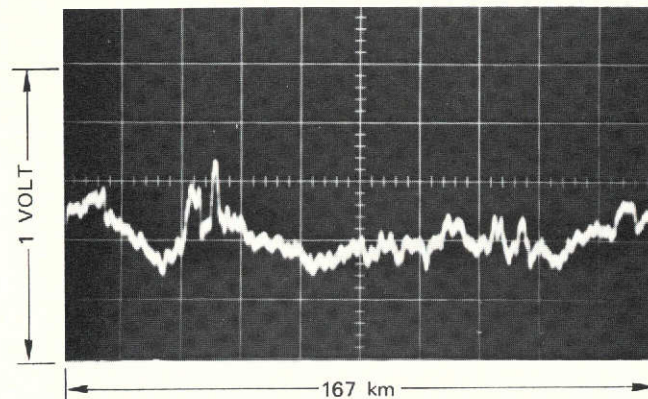
2. Services and Products

Dr. Turner spent 29 and 30 November 1973 working on the Console with images of grasslands and phreatophyte growth in Central Arizona. At that time, a technique and program for future processing of his imagery by SRI and personnel were agreed upon:

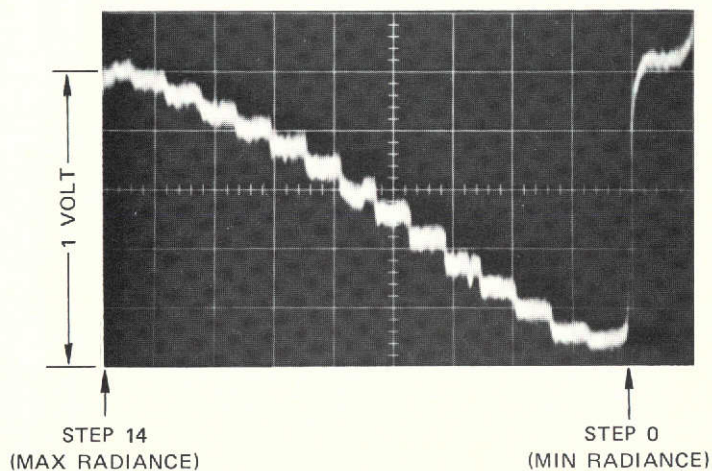
- (a) Make measurements and provide densitometry traces for the Avra Valley Transect, the Old Baldy Transect, and the Mine Transect.
- (b) Make time lapse studies of both the Benson and Sabino Canyon phreatophyte areas.

A principal objective of Dr. Turner's research was the mapping and quantitative documentation of these areal changes. Consequently, SRI investigated various methods of displaying radiance profiles along selected transects (see Figures 24a and b) as well as creating binary thematic masks (thresholdings) (see Figure 25) of scenes that appear representative of the scenes observed visually and at the same time are amenable to measurement.

Because of the relatively cloud-free location of his test sites, Dr. Turner accumulated the largest file of sequential imagery (some 24 cycles of usable data) of any of our investigators. As a result, time lapse was used extensively in the analysis work. Systematic changes in areal extent of the vegetated regions are clearly visible

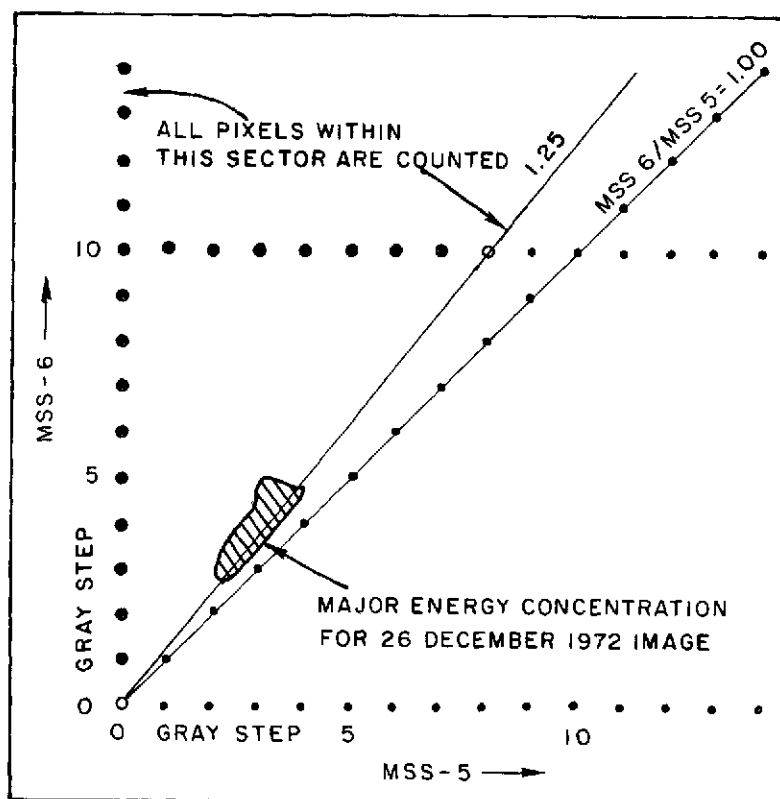


(a) RADIANCE PROFILE ALONG MINE TRANSECT IN ARIZONA DESERT USING ERTS-1 FRAME 1102-17280-5. [VERTICAL SCALE AND dc LEVEL SAME AS FOR GRAY SCALE SHOWN IN PANEL b]

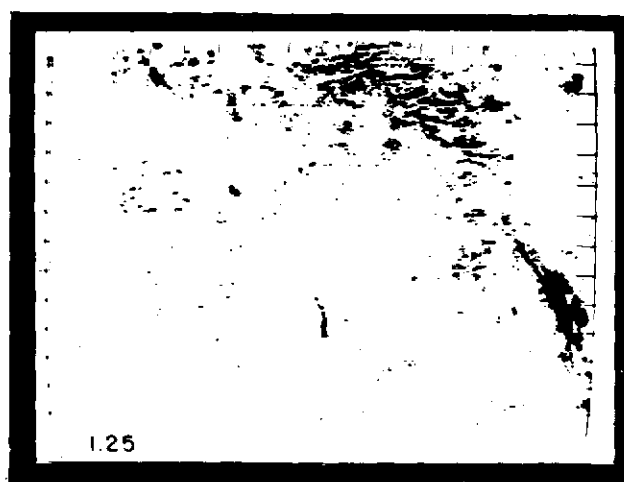


(b) VIDEO SIGNAL RESPONSE FOR SCAN ACROSS CALIBRATION GRAY SCALE OF POSITIVE TRANSPARENCY OF ERTS-1 FRAME 1102-17280-5 USED FOR PANEL a, ABOVE

FIGURE 24 EXAMPLES OF RADIANCE PROFILE DISPLAYS



(a) SKETCH OF COLOR-SPACE DISPLAY SET TO A BAND 6/BAND 5 RATIO OF 1.25:1 (DOT ROW ACROSS MSS-6 AT STEP 10 INTENSIFIED TO FACILITATE MAKING RATIO ADJUSTMENTS)



(b) BINARY MASK RESULTING FROM BAND 6/BAND 5 RATIO OF 1.25:1

FIGURE 25 EXAMPLES OF SLICING DISPLAYS, CYCLE 9, 26 DECEMBER 1972,—AVRA VALLEY, ARIZONA

while watching the time-lapse replays of these sequences, and especially so in color.

Dr. Turner revisited SRI during the week of 14 May 1974 and used the ESIAC to study additional imagery (MSS 5 and 6) of desert vegetation for the Tucson area. Registered color sequences for ten then available ERTS cycles were prepared for two major test regions designated as Avra Valley and Old Baldy. A procedure<sup>\*</sup> was evolved for deriving thematic masks in accordance with the ratio of radiances observed in MSS 6 to those observed in MSS (see Figure 25a). Bare desert soil exhibits a ratio very close to unity. It was found that the typically sparse desert vegetative cover increases the bare desert ratio to values between unity and 2.0. With reasonable care in compensation for film density variations during the process of scanning with the ESIAC, it has proven feasible to generate thematic masks which are TRUE for all areas where the radiance ratio exceeds threshold values as small as 1.1 or 1.2. The newly added color space display described in Section II of this report was used to set the various ratios used in the thematic extractions.

Dr. Turner revisited SRI the week of 16 July, 1974. At that time, to arrive at an acceptable ratio, thematic masks of vegetative cover were derived for several cycles using a number of ratios--1.2, 1.25, 1.3, 1.5, and 2.0. An example of the change in cover that results

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\* A sketch of the color space display of a typical desert scene plus its calibration gray step is shown in Figure 25a. Note that to facilitate adjustment of the ratioing controls, a second row of band 6 gray scale calibration dots has been located to intersect the band 6 gray scale at step 10. With the ratioing and thresholding properly set, and the display intensified with the resulting thematic mask video signal, only those regions above and to the left of a diagonal line between the origin and gray step 8 on this auxiliary calibration axis will be displayed (and counted) for this ratio of 1.25.

from these small ratio changes is shown in Figure 26. It is obvious that less vegetative coverage is delineated as higher values are used. On the basis of known distributions of cover at this time, Dr. Turner decided that the ratio of 1.25 was the more acceptable one. The ability to skip rapidly back and forth through registered color sequences was of great help in arriving at an acceptable threshold for the ratio. This value was used to derive subsequent measurement values for the Serrita Mine and Mile-Wide sites (Tucson and Avra Valley area) and were used for the evaluation of the Sabino Canyon and Benson areas.

Dr. Turner again visited SRI during the week of 25 February-1 March 1974 for the purpose of obtaining additional measurements of vegetation cover over his test sites (Tucson, Arizona and surrounding territory) for additional ERTS cycles. Registered color sequences for these ERTS cycles were prepared for the major sites entitled Tucson and Avra Valley. Thematic masks, created by counting all picture elements where the band 6/band 5 radiance ratio exceeded 1.25, were used to evaluate the vegetation cover.

To facilitate further checking against ground truth, and to provide documentation for the work, a set of registered images, overlays, and radiance profiles for each area measured was prepared by photographing the ESIAC displays. A typical set of data provided to Dr. Turner for the Tucson, Avra Valley, Sabino Canyon, and Benson test sites included the following items:

- (a) Scene photo
- (b) Scale (kilometer) grids
- (c) Transect overlay
- (d) Calibrated radiance profile
- (e) Ratio overlays (diaz transparencies)
- (f) Area measurements for the ratio overlays.

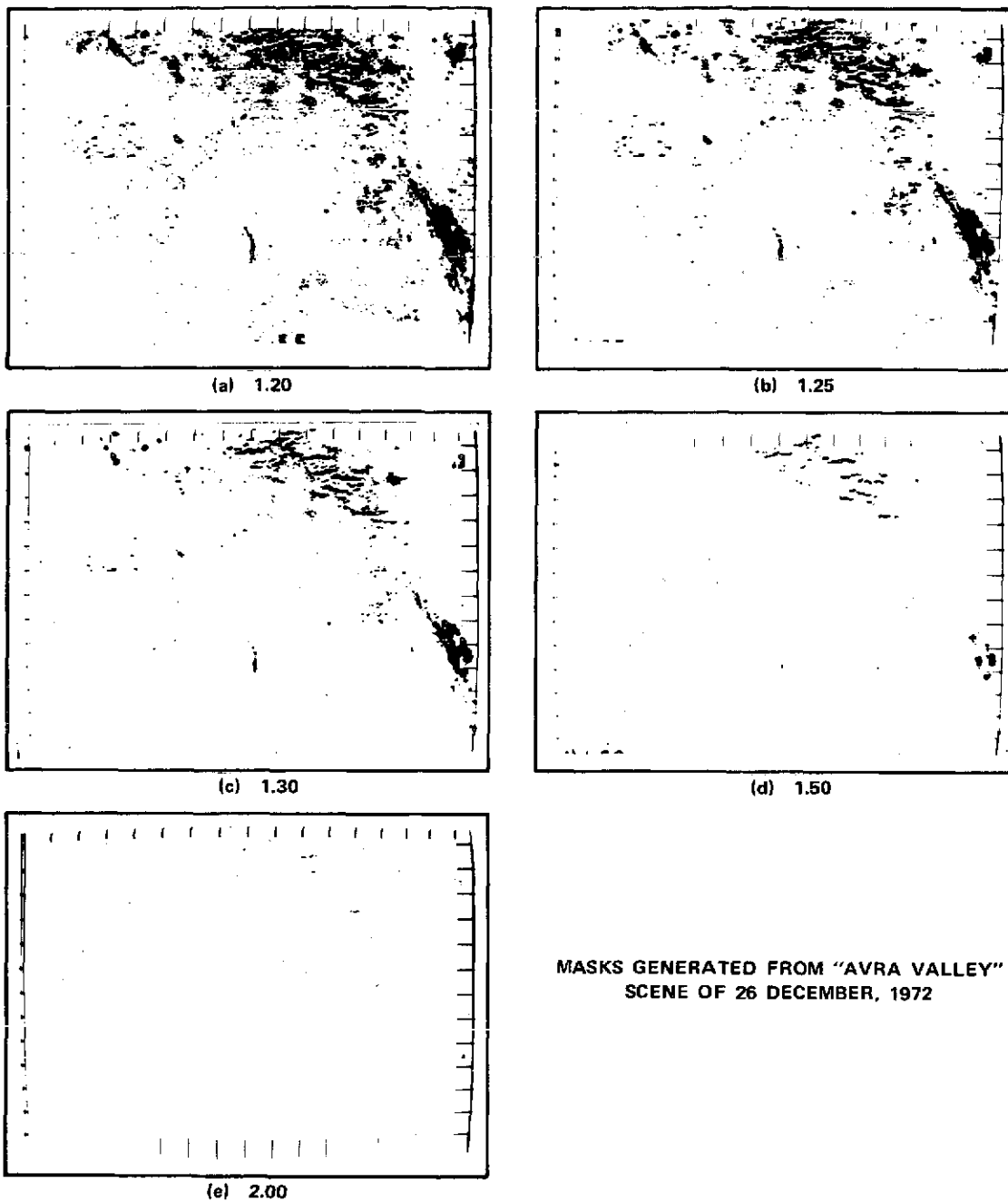


FIGURE 26 EXAMPLES OF THEMATIC MASKS GENERATED USING SELECTED RATIOS OF BAND 6 (MSS-6) TO BAND 5 (MSS-5)  
Ratio values indicated below each panel.



A complete listing of the cycles analyzed for the four respective test sites is shown in Table 4.

C. Fresh Water Dynamics Dr. E. J. Pluhowski (IN058) USGS, WRD,  
Arlington, Virginia

1. Tasks

Study patterns and pattern changes of sediment plumes and shoreline erosion generated by the Niagara, Genesee, and Oswego Rivers.

Study the movement of these riverborne sediments into, as well as in, Lake Ontario.

2. Services and Products

Dr. Pluhowski visited SRI on 20-22 March 1973, bringing with him available cloud-free 70 mm color separation transparencies for the Lake Ontario area through January 1973. ESIAC was used to enhance and display sediment plumes and shoreline erosion for the following estuaries:

- (1) Port Dalhousie Harbor
- (2) Welland Canal
- (3) Genesee River

Additionally, several examples of shoreline erosion were detected in the imagery, especially in frame 1137-15355. The Niagara River plume was not directly distinguishable. Under certain conditions, however, its boundaries could be inferred. Surprisingly, the Niagara River usually appeared less turbid than the ambient lake water, so that its signature was difficult to discern.

Dr. Pluhowski again visited SRI the week of October 16, 1973 for the purpose of studying the patterns and pattern-changes of sediment plumes in the vicinity of

Table 4

LIST OF CYCLE NUMBERS FOR WHICH SELECTED  
DESERT TEST SITES COULD BE EVALUATED

Cycle No.	Date	Test Sites			
		Tucson	Avra V.	Sabino C.	Benson
1	5 Aug 72	---	---	---	---
2	23 Aug 72	---	X	X	X
3	9 Sept 72	---	---	---	---
4	27 Sept 72	---	---	---	---
5	16 Oct 72	---	---	---	---
6*	3 Nov 72	X	X	X	X
7	21 Nov 72	---	---	---	---
8	9 Dec 72	---	---	---	---
9*	27 Dec 72	---	---	X	X
10*	14 Jan 73	---	X	X	X
11*	1 Feb 73	---	X*	---	---
12*	19 Feb 73	---	---	X	X
13	9 Mar 73	---	---	---	---
14*	26 Mar 73	---	---	X	X
15*	13 April 73	---	X	X	X
16*	1 May 73	---	---	X	X
17*	19 May 73	X	X	X	X
18*	7 June 73	---	X	---	X <sup>†</sup>
19*	25 June 73	X	X	X	X
20	13 July 73	---	---	---	---
21	31 July 73	---	---	---	---
22*	18 August 73	---	X	---	---
23*	5 Sept 73	X	X	X	X
24*	23 Sept 73	X	X	X	X
25*	10 Oct 73	X	X	X	X
26	29 Oct 73	---	---	---	---
27*	14 Nov 73	X	X	X	X
28	3 Dec 73	---	---	X	X
29	21 Dec 73	---	---	X	X
30	8 Jan 74	X	X	X	X
31	26 Jan 74	---	---	---	---
32	13 Feb 74	---	---	---	---
33	4 Mar 74	---	---	---	---

All Patagonia scenes except as indicated.

\* From "Sells" images.

† From "Portal" images.

- (a) South Shore - Lake Ontario
- (b) Central Ontario (Genesee River)
- (c) W. Central Ontario
- (d) Niagara - Western Region
- (e) Eastern Ontario

from ERTS scenes dating from 20 August 1972 through 3 September 1973. Interpretation of these patterns were made by Dr. Pluhowski in viewing these scenes in color on the ESIAC using various combinations of MSS 4-5-6 or 7. Considerable time was spent in judging which combination of spectral bands and color display primaries yielded the most detail. Colored 35 mm photoprints were made of each pattern as seen on the ESIAC color monitor. Figure 27 is an example of this type of product. Dr. Pluhowski began to exploit the trend-enhancing power of time-lapse viewing of this imagery. The available time-lapse sequence, for example, showed the strong dependence of plume distributions upon wind direction and speed in the lake.

Dr. Pluhowski also spent 7-9 May 1974 at SRI completing his analysis of the ERTS data.

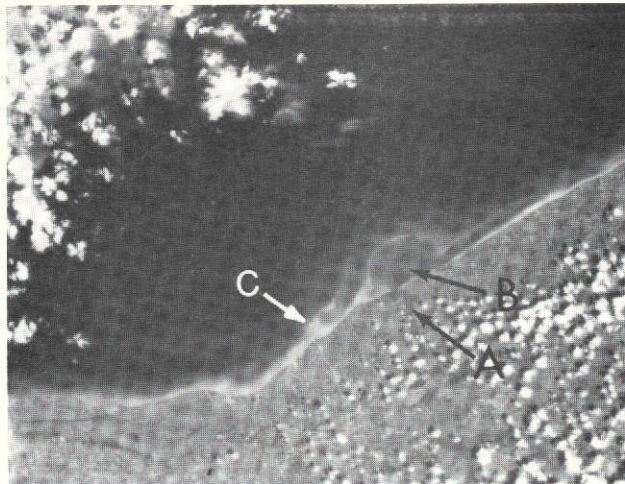
D. Estuarine Dynamics Dr. Fred Ruggles (IN395) USGS, WRD,  
Hartford, Connecticut

#### 1. Tasks

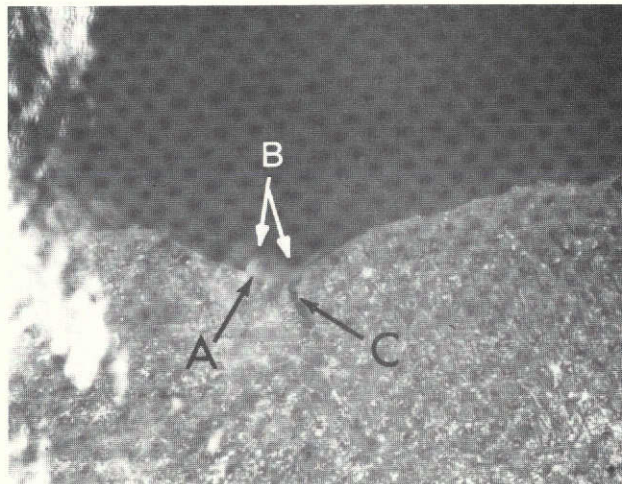
Measure plume development at the mouth of the Connecticut River in Long Island Sound. Study mixing patterns of estuarine discharges into Long Island Sound.

#### 2. Services and Products

Dr. Ruggles visited SRI in late August 1973. At that time, ESIAC was used to enhance the visibility of patterns caused by the suspended sediments in the waters of the Connecticut, Thames, and Housatonic



(a) ERTS-1 IMAGE OBTAINED 12 APRIL 1973, SHOWING THE NIAGARA RIVER (A), THE NIAGARA RIVER PLUME (B) AND HIGHLY TURBID WATER EMANATING FROM THE WELAND CANAL (C).



(b) ERTS-1 IMAGE OBTAINED 16 MAY 1973 SHOWING THE MOUTH OF THE GENESEE RIVER (A), A 26 sq km TURBIDITY PLUME GENERATED BY THE GENESEE RIVER (B), AND IRONDEQUOIT BAY (C).

FIGURE 27 EXAMPLE OF IMAGE ENHANCEMENT TO REVEAL TURBIDITY PLUMES

Rivers, and to study the mixing patterns of estuarine discharges into Long Island Sound at different phases of the tidal cycle. On 10 November 1973, Dr. Ruggles personally completed his data measurements and interpretations using enhancement of static scenes, as well as time-lapse sequences, displayed on the ESIAC. The typical product supplied Dr. Ruggles was similar to that supplied Dr. Pluhowski.

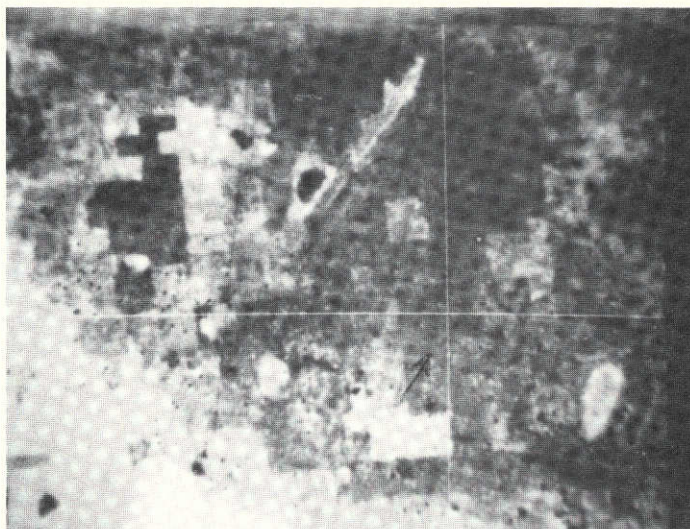
E. Playa Lake Dynamics Dr. C. C. Reeves (IN168), Texas Tech University, Lubbock, Texas

1. Tasks

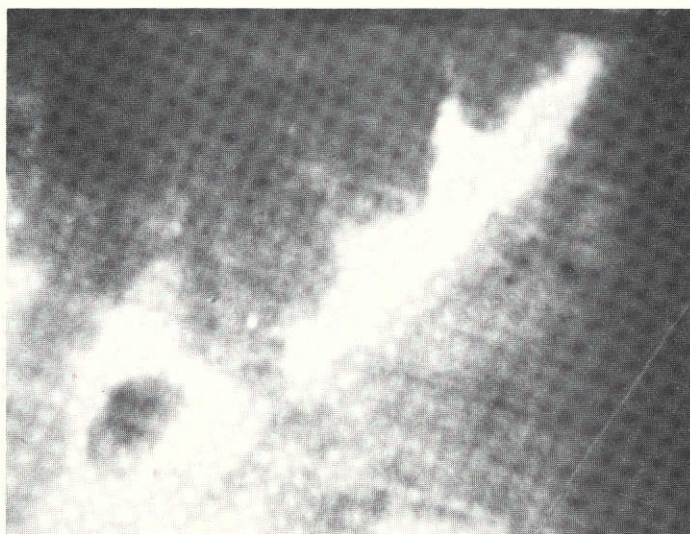
Determine numerically (a) how many lake basins contain water and (b) how much area is covered by the water surface over the Southern High Plains of Texas. Determine the area of the Double Lakes and T-Bar Playa that are covered by water.

2. Services and Products

Dr. Reeves visited SRI from 24 September through 28 September 1972. At his request, ERTS scenes (MSS 5 and 7) for the "Lubbock Area" and the "Double Lakes" area were entered in ESIAC for 11 cycles from 29 July 1972 through 24 July 1973. Figure 28 is an example of this type of ESIAC presentation. The scene, "Lubbock Area," covers about 70 km high; the "Double Lakes" area, entered at maximum zoom capability, covers 9 km high. Dr. Reeves viewed both scenes via time-lapse mode and via slicing techniques. Particular attention was paid to the Double Lakes area. Both the South Playa and the North Playa of the Double Lakes area were sliced, individually, for coverage of water only, and also of water plus mud. These area counts will be compared by Dr. Reeves to ground-truth data. A series of film sequences were prepared at SRI showing the changes of the Lubbock area and Double Lake region through the date sequence noted above, as viewed on MSS-5 band alone, MSS-7



(a) VIEW OF PLAYAS: LUBBOCK AREA



(b) ENLARGED VIEW OF NORTH AND SOUTH PLAYA LAKES. NOTICE HOW THE WET PLAYA MUD OF THE NORTHEASTERN PLAYA IMAGES COMPARES TO THE WATER IN THE SOUTHWESTERN PLAYA. BAND 5.

FIGURE 28 EXAMPLES OF THEME ENHANCEMENT OF PLAYA LAKES

band alone, and in combination, to create various "false color" presentations. In addition, both slow-frame speed sequences (1 frame per second) and fast-frame speed sequences (3 frames per second) were prepared. These nine film sequences were combined into a film loop for presentation by Dr. Reeves at the NASA Conference held 23 October - 2 November 1973.

Dr. Reeves was at SRI from 10 October through 14 October 1973, examining available techniques for data processing of ERTS-A data for the Water Budget of the Texas High Plains Playa lakes.

The area-measuring capability of ESIAC was used to compile statistics on water areas within specific playas and totals for the hundreds of others within an ERTS frame. Additionally, time-lapse sequences were searched for patterns in lake-fill distribution that might correlate with geographical, meteorological, or seasonal conditions.

In summary, the typical products supplied Dr. Reeves included:

- (a) Enhancement of the water and mud areas of the playas
- (b) Measurement of water and mud areas of the playas
- (c) Enhancement of wet lakes in the Southern High Plains
- (d) Accurate registration on TV monitor for the production of time-lapse film strip.

F. Watershed Dynamics Dr. Este P. Hollyday (IN389) USGS, WRD,  
Nashville, Tennessee

1. Tasks

Determine the degree to which ESIAC could be used in enhancing, identifying, and mapping the following four major categories of "themes":

- Healthy vegetation
- Exposed water surface



- Snow
- Massed works of man.

## 2. Services and Products

Dr. Hollyday visited SRI on 3, 4, and 5 April 1973. Virtually all of the time was devoted to working with ESIAC to display imagery brought by him. Some time was spent studying single-band and multi-band enhancements at various scales of various regions in the Delaware-Chesapeake Bay region for fall and early winter. Color photographs were made of enhanced imagery, and trial binary thematic masks were made by amplitude thresholding single-band signals within specific drainage basins. These were compared with similar theme extractions which had been made manually. Spectral signatures taken from ESIAC in common regions were compared in time-lapse mode for analytic purposes. Figure 29 is an example of a type of data product supplied Dr. Hollyday, showing the use of time lapse to discriminate riparian vegetation. Radiance values along a cursor trace through the Pocomoke River swamp quantified the discrimination of riparian vegetation in winter 1973 as compared to fall 1972.

In the week of 12 August 1973, Dr. Hollyday again visited SRI. A significant amount of Dr. Hollyday's proposed work entailed the measurement of integrated clear areas from binary transparencies (theme foils) prepared by non-SRI personnel, either photographically or manually. While such measurements can be made with the ESIAC, a brief side excursion was made to investigate the possibility that equivalent or superior accuracy for this particular measurement might be achieved with far simpler and less expensive equipment. Accordingly, a separate set-up using a photographic enlarger and an integrating photometer was prepared for Dr. Hollyday and used by him in measuring areas within specific drainage basins for several sets of previously prepared thematic



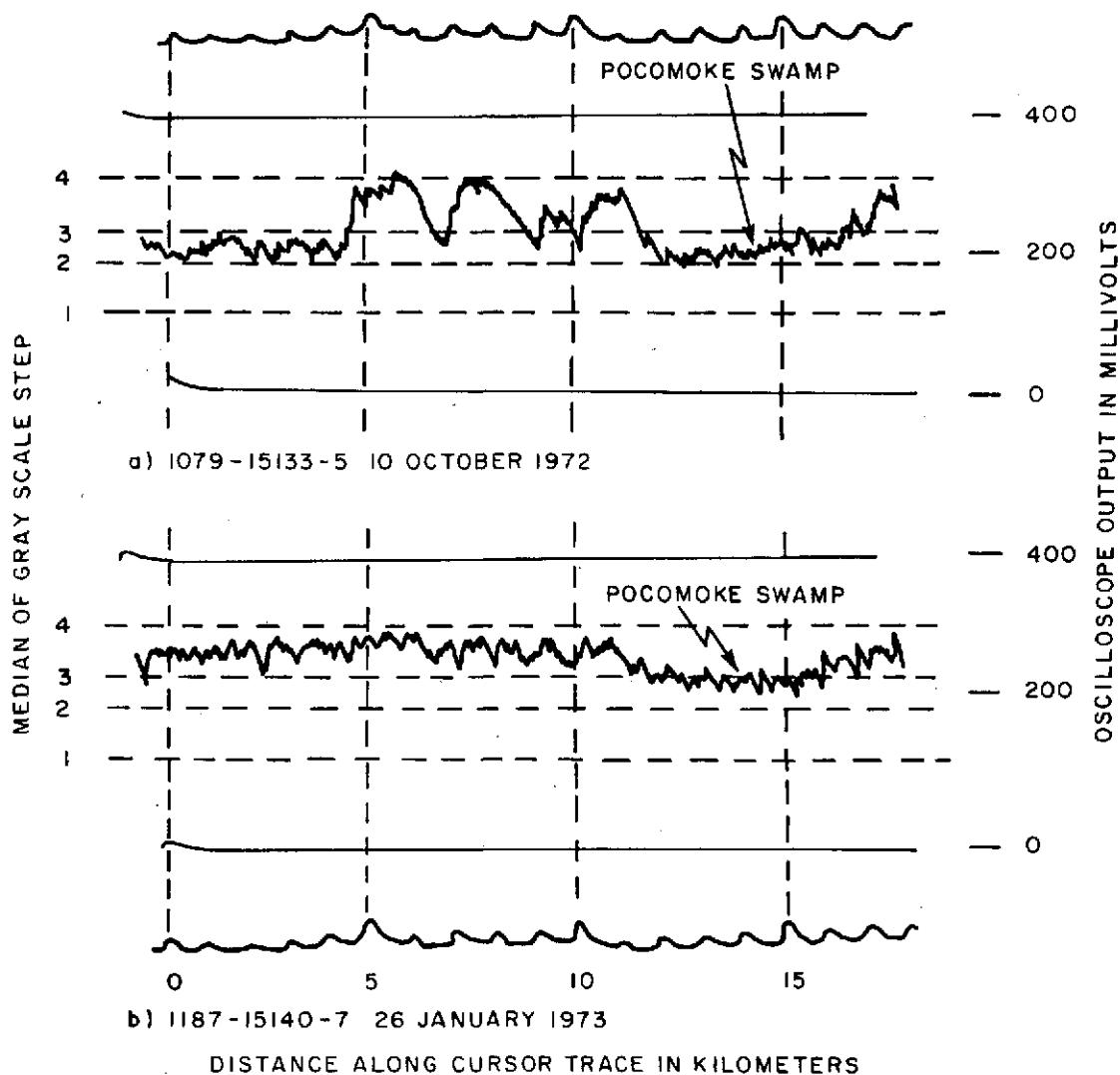


FIGURE 29 EXAMPLE OF TIME-LAPSE FOR DISCRIMINATION OF RIPARIAN VEGETATION

extractions. Calibration checks of this procedure, using carefully measured apertures of various sizes, verified that accuracies of  $\pm 2\%$  of the basin area were easily attainable. This is better than the  $\pm 5\%$  which is believed to be required in order to make meaningful stream-flow regression estimates, and appears to be many times more accurate than the actual thematic extraction can be made by any process evolved to date. As a result of these tests, a recommendation was made that in the future, any significant quantity of area measurements of this type be made with the simpler equipment.

G. Everglade Water System Mr. G. E. Coker, USGS, WRD,  
Tampa, Florida

1. Tasks

Identifying and mapping water changes over the Everglades.

2. Services and Products

Mr. C. E. Coker visited SRI from 4 June through 8 June 1973. The initial part of the visit was spent in demonstration of ESIAC and experimenting with procedures offering the best possibility for detecting water changes over the Everglades. Only three cycles (11, 12, and 13) were available and of these, cycle 11 was 50% cloud covered. However, all three cycles were entered into the ESIAC, and color displays were made of various band combinations. The decision was made that a combination of band 5 (in cyan) with band 7 (in red) offered the best choice for detection of water changes. However, for these particular scenes, band 7 by itself, displayed in monochrome and at high contrast, was almost as good.

Radiance profiles were recorded on four transects in conservation area #1 (upper part of Everglades) for each of the cycles. The water change was observed both by time lapse and by displays of date-to-date difference images. Numerous photographs were taken of the displays. These types of products are similar to those supplied Dr. Reeves and Dr. Turner (see Sections IV.B and IV.F, respectively).

## V VISITS AND CONFERENCE PRESENTATIONS

### A. Visits to SRI (nonparticipating USGS investigators)

The following visits to SRI can be reported; all expressed an interest in ESIAC and in the work being accomplished under the NASA Contract.

Geof Albert	NASA (Philco)
Albert Arking	NASA GSFC
Ralph Avrag	WSMR
J. C. Bass	Plessey Company, England
P.E.G. Bates	Plessey Company, England
W. Bandeen	NASA GSFC
J. Billingsly	NASA GSFC
Virginia Carter	USGS, Washington
Dr. C. Collins	NSF
M. Coon	Seattle, Washington
Earl Davis	State of California
R. Devereux	NSF
M. Deutsch	USGS
N. Durocher	NASA Hdqtr.
K. Ejiri	Hitachi, Tokyo, Japan
W. Fisher	USGS
Dr. Hall	Management Consultants, Berkeley
L. Hubert	NOAA
J. Johnston	USGS, Washington
M. Kolopinski	Dept. of Interior, San Francisco
J. H. Hong	Ministry of Science & Inds., Korea
Dr. Kunii	IBM
E. Latham	USGS
F. Limpert	Bonneville Power Authority
K. Mura	Fujitsu
N. Murayama	JMA, Japan
R. Nagle	U.S. Navy
W. Nordberg	NASA GSFC
V. Oliver	NOAA
A. Rango	NASA GSFC
J. Rassmussen	University of Arizona

Marvin Kays	WSMR
R. Reynolds	WSMR
C. J. Robinove	USGS
D. Rockwood	Corp of Engineers, Portland, Wash.
V. Salomonson	NASA GSFC
W. Simon	USGS, Menlo Park
H. Schumann	USGS, Phoenix, Arizona
W. Shenk	NASA GSFC
Prof. Hidetosi Takahasi	Tokyo University
W. R. Thomas	Plessey Company, England
Don Wisnet	NOAA

#### B. Conferences Attended

The following conference attendance by SRI investigators can be reported:

- NASA ERTS-1 Symposium, Goddard Space Flight Center, 5-9 March 1973: S. M. Serebreny and W. E. Evans.
- EROS Conference, Sioux Falls, South Dakota, 30 October through 1 November 1973: W. E. Evans.
- Recent Status of Accomplishments, Earth Resources Discipline Panel and Working Group in Interpretive Techniques at Goddard Space Flight Center, NASA, 23 October through 2 November 1973: S. M. Serebreny.
- Third ERTS Symposium sponsored by NASA/Goddard Space Flight Center, Washington, D.C., at the Statler-Hilton Hotel 10-14 December 1973: S.M. Serebreny.
- The 54th Annual Meeting of American Meteorological Society, Honolulu, Hawaii, 8-11 January 1974: S. M. Serebreny and P. A. Davis.
- Western Snow Conference, Anchorage, Alaska, 16-19 April 1974: W. E. Evans.

#### C. Abstracts of Papers Presented

- NASA ERTS-1 Symposium, 5-9 March 1973

ANALYSIS OF ERTS IMAGERY USING SPECIAL  
ELECTRONIC VIEWING/MEASURING EQUIPMENT

W. E. Evans and Sidney M. Serebreny  
Stanford Research Institute  
Menlo Park, California

ABSTRACT

An Electronic Satellite Image Analysis Console (ESIAC) is being employed to process imagery for use by USGS investigators in several different disciplines studying dynamic hydrologic conditions. The ESIAC provides facilities for storing registered image sequences in a magnetic video disc memory for subsequent recall, enhancement, and animated display in monochrome or color. Quantitative measurements of distances, areas, and brightness profiles can be extracted digitally under operator supervision. Initial results are presented for the display and measurement of snowfield extent, glacier development, sediment plumes from estuary discharge, playa inventory, and phreatophyte and other vegetative changes.

- Second Annual Remote Sensing of Earth Resources Conference, University of Tennessee Space Institute, Tullahoma, Tennessee, 26-28 March 1973.

TIME-LAPSE ANALYSIS OF ERTS IMAGERY  
USING SPECIAL ELECTRONIC  
VIEWING/MEASURING EQUIPMENT

W. E. Evans  
Stanford Research Institute  
Menlo Park, California

ABSTRACT

To investigate the potential of time-lapse analysis of ERTS imagery, an Electronic Satellite Image Analysis Console (ESIAC) is being employed to process imagery for use by USGS investigators in several different

disciplines studying dynamic hydrologic conditions. The ESIAC provides facilities for storing registered image sequences in a magnetic video disc memory for subsequent recall, enhancement, and animated display in monochrome or color. Quantitative measurements of distances, areas, and brightness profiles can be extracted digitally under operator supervision. Applications to date have included display and measurement of snowfield extent, sediment plumes from estuary discharge, glacier development, playa inventory, and phreatophyte and other vegetation changes. Color slides and movies illustrating initial results accompany the oral presentation.

- Third ERTS Symposium, Washington, D.C., 10-14 December 1973.

#### ESIAC, A DATA PRODUCTS SYSTEM FOR ERTS IMAGES

S. M. Serebreny and W. E. Evans  
Stanford Research Institute  
Menlo Park, California

#### ABSTRACT

An Electronic Satellite Image Analysis Console (ESIAC) has been developed for visual analysis and objective measurement of Earth Resources Imagery. The system is being employed to process imagery for use by USGS investigators in several different disciplines studying dynamic hydrologic conditions. The ESIAC provides facilities for storing registered image sequences in a magnetic video disc memory for subsequent recall, enhancement, and animated display in monochrome or color. The unique feature of the system is the capability to time-lapse the ERTS imagery and analytic displays of the imagery. Data products have included quantitative measurements of distances and areas, brightness profiles, and movie loops of selected themes.

The applications of these data products are identified and include such diverse problem areas as measurement of snowfield extent, sediment

plumes from estuary discharge, playa inventory, and phreatophyte and other vegetation changes. A short movie is presented to demonstrate some uses of time-lapse presentation in these investigations. A comparative ranking of the electronic system in terms of accuracy, cost effectiveness, and data output shows it to be a viable means of data analysis.

- Western Snow Conference, Anchorage, Alaska, April 1974.

#### PROGRESS IN MEASURING SNOW COVER FROM ERTS IMAGERY

W. E. Evans

Stanford Research Institute  
Menlo Park, California

#### ABSTRACT

A hybrid of digital and analog analysis techniques is being employed to determine the accuracy with which snow area and temporal change in snow area can be determined from satellite imagery.

The principal analysis tool is an Electronic Satellite Image Analysis Console (ESIAC) which permits display of time-lapse sequences of color composite images on a color TV monitor. Binary snow maps are generated electronically, superimposed on the image display for any necessary human editing, and then measured for area in a digital counter. Results are checked against high altitude aircraft photography.

Bright snow is relatively easy to measure. Snow in shadow or illuminated at low incidence angles is harder to identify unambiguously. Several potential solutions for this problem and for the problem of a snow-tree mixture are being studied. A time-lapse movie covering a full year of ERTS imagery of a typical mountain snowfield will be shown.

- 54th Annual Meeting of American Meteorological Society,  
Honolulu Hawaii, 8-11 June 1974.

## SATELLITE APPLICATIONS TO WATER STORAGE

Sidney M. Serebreny\*  
Dr. Paul A. Davis†

Stanford Research Institute  
Menlo Park, California

### ABSTRACT

A technique has been developed for estimating basin precipitation (rain and snow) by using operational meteorological satellite data. Best results are expected for cumulative precipitation totals over periods of 5 days or longer, but reliable evaluation of results is a problem. The study has expanded to an analysis of the rate of change of surface water storage, with initial emphasis on the rate of change of snowpack during the melt season as viewed by ERTS-1 imagery. Estimated rates of change of storage and runoff are influenced by precipitation occurring between successive ERTS views. On the other hand, accurate future accounting of storage changes and the processes of water loss will enable better evaluation of estimates of cumulative precipitation.

Typical problems in the assessment of snowpack extent and rate of change are examined by comparison with snow course measurements at specific locations in the basin. Sequences of ERTS images are displayed, as are select imagery from the NOAA-2 satellite.

A color movie will be presented using a series of ERTS frames to illustrate the use of electronic techniques to depict changes with time of the areal coverage of snow as well as to provide quantitative measurement of these changes.

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\* Assistant Director, Atmospheric Sciences Laboratory.

† Program Leader, Satellite Radiometric Data Applications.



- Symposium on Applications of Satellite and Airplane Remote Sensing of Natural Resources in the Pacific Northwest, sponsored by Washington State Department of Natural Resources USGS-EROS, NASA-AMES, ASP-Puget Sound, & PNWRSTF, Tumwater, Wash., 2 May 1974.

## TIME-LAPSE TECHNIQUES IN ANALYSIS OF SATELLITE IMAGERY

W. E. Evans  
Stanford Research Institute  
Menlo Park, California

### ABSTRACT

Because of its precisely repetitive nature, imagery from geosynchronous and Earth Resources satellites is ideally suited to study and analysis by means of time-lapse display. By this means, temporal changes become dramatically apparent and subtle permanent features become enhanced and identifiable through a surprisingly large amount of cloud cover and other extraneous clutter. While time-lapse sequences can be prepared photographically, the required registration, scaling, and color balance procedures are quite time consuming. At SRI, the set-up time has been significantly shortened and the display process made interactive through the effective use of relatively standard television animation, editing, and magnetic recording techniques.

The hardware is called ESIAC for Electronic Satellite Image Analysis Console. In addition to display in both monochrome and color, the ESIAC provides means for making quantitative measurements of displacements, areas, and radiances and for creating binary thematic maps based on multispectral decisions. The talk was illustrated with short movie sequences showing several methods of measuring extent of snow cover in the mountainous regions of the Pacific Northwest.

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